Bare tool design to overcome overcut problem in ECM process

Dadge Mukesh Shamrao*, Ravi Butola, Ranganath M. Singari

(Delhi Technological University, Delhi, India)
*Email: mukehshnitw@gmail.com

Abstract : *Electro-chemical machining (ECM) is one of the mass production method for machining of hard and tough alloys. Drilling a straight with a bare tool contributes to side machining also.Hence taper is observed. One of the solutions is to provide side insulation but in this paper bare tool is designed to reduce overcut without insulation. The Electrochemical machining (drilling) has been studied experimentally with the existing bare step tool-1 (electrolyte copper) and EN8 work material considering with overcut and operating parameters like feed rate, gap length between cathode and anode and voltage. A new bare taper tool (tool-2) has been made to reduce the overcut and bottom diameter has been reduced but overall overcut remain same then again A new taper tool (tool-3) made to reduce the overcut and it reduced to 0.8 mm concerning with bottom diameter. Final curve fitting is done with regression equation.*

Keywords: *Bare tool design ,Electro-chemical machining (ECM) , overcut*

I INTRODUCTION

Electrochemical machining is one of the non-traditional machining process. It is just reverse of electroplating where anodic dissolution is of great importance. So in ECM Catode and anode will be tool and workpiece respectively.[1,9]. In this process tool is just replica of the part to make.

Fig1.Electrochemical principle

It is production process for machining conducting materials with reasonable surface finish chip removal rates on repetitive work. Material removal is carried out by maintaining an electrolyte between the cathode and the anode in a very small gap by pumping electrolyte between the gap.In drilling of parts there will be no burr and distortion in holes . A great deal of hydrogen is evolved at the cathode. In this process the temperature generated are low which do not cause metallurgical changes in the workpiece material.[2,3,7].NaCl is taken as electrolyte due to easy availability, cheap , noncorrosive and high current efficiency[10]. surface quality is drawback for NaCL. Radial overcut has been studied with respect to feed rate, gap between tool and workpiece and voltage . Regression analysis has been done to find out bare tool (without insulation) shape to reduce overcut.

II ECM SET-UP AND THEIR ELEMENTS

Table 1: Elements of ECM process

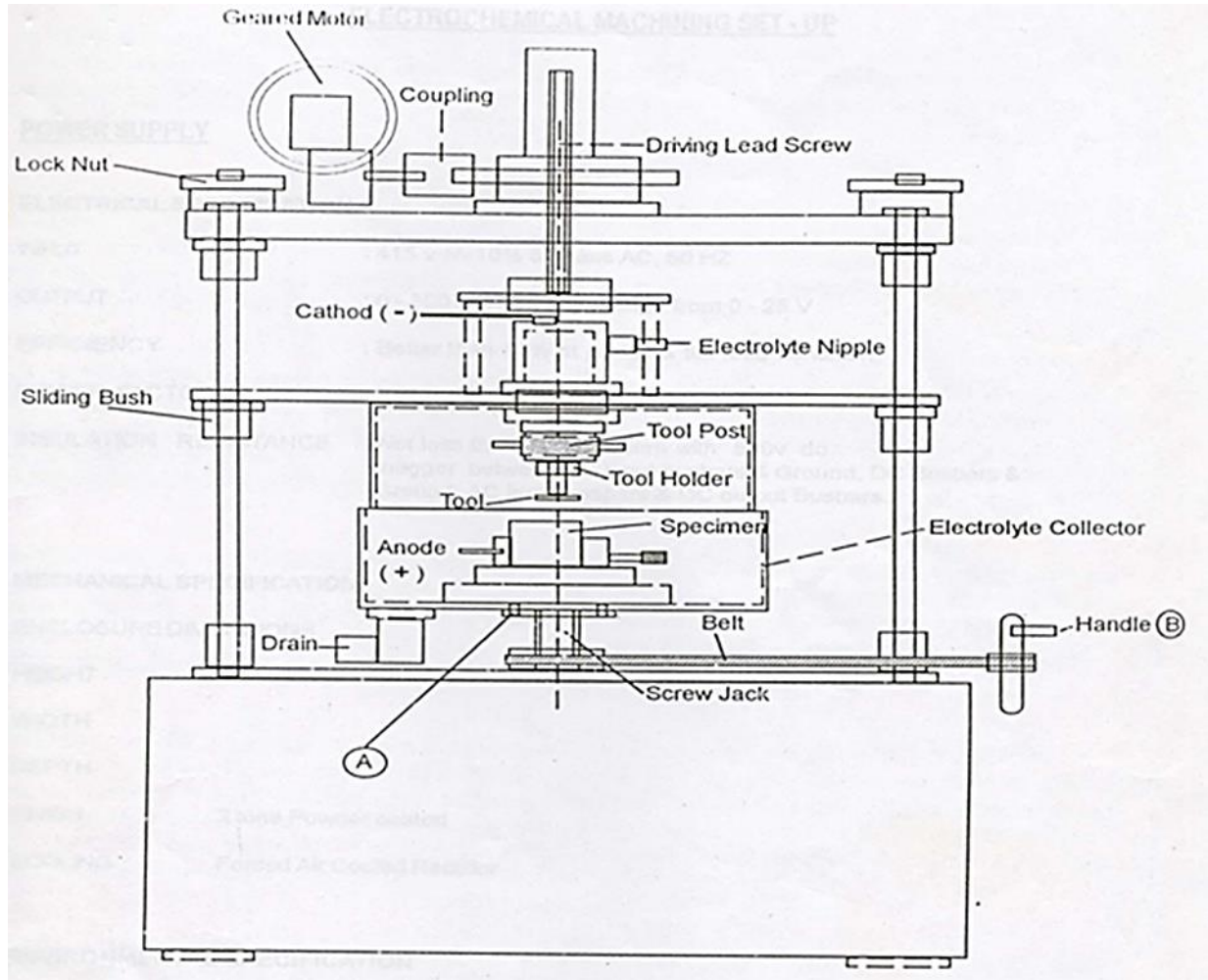| Elements of ECM ↓	Material	Motion
Work	EN8	Stationary
Tool	Copper	linear vertical motion w.r.t bed.
Electrolyte	aqueous solution of common salt NACL	presserised at maching work area
Power source	Input: 415 v +/-10% 3 phase AC 50HZ Output: 0-300A dc at any voltage from 0-25v.	

Fig. 2 ECM SET-UP

Table. 2 Machine specifications

Voltage	: 0-25 volts
Feed	: 0.1- 6.28 mm/min
Ammeter	: 0-300 amp
Timer	: count down experiment time
Machining mode	: manual mode

Electrolyte and its flow system

Electrolyte must be discarded frequently or reclaimed by neutralizing with NAOH and centrifuging to remove hydroxides. Cathode tool becomes platted with a black smut and so must be cleaned frequently to certain accuracy. Water is poured in to the reservoir unto certain level, after that 15% of salt is added to 120 liters of water. Then salt water is stirred to get uniform distribution of salt in the solution.
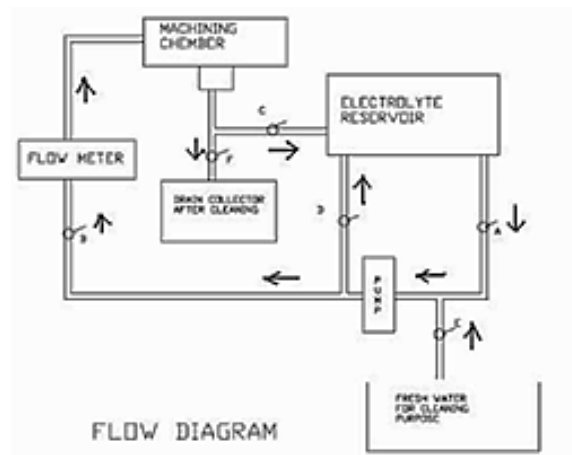

Fig. 3 Flow diagram of electrolyte

Tool and tool feed system

Copper is selected as a tool material. Use of non-corrosive and electrically non-conducting materials for making fixtures is recommended. Also, the fixtures and tools should be rigid enough to avoid vibration or deflection under the high hydraulic forces to which they are subjected.

Work piece And Work holding System:
Work holding devices are made of electrically non conductive materials having good thermal stability, and low moisture absorption properties.EN8 grade steel is taken and it is cut into required lengths by *Sawing Machine*. The work piece is flattened by Shaper Machine. After that Super finishing is done by using Surface Grinding Machine.

III PROCEDURE AND TOOL DESIGN THEORY

An initial inter-electrode gap of 0.5 mm was set before the start of machining. After ensuring proper electrolyte flow, power supply and feed to the tool were switched on. To ensure the flushing of sludge, drilling was interrupted by switching off the power for 30 s after every 5 min of machining, while maintaining the flow of electrolyte. In all experiments, blind holes were made in the work samples. Drilling was stopped when when it reached to certain depth. After completion of each experiment, the workpiece was properly cleaned. The workpiece was then taken and the diameter of the drilled hole was measured with a vernier callipers.

During electrochemical drilling process drilling a straight hole involves a bare tool, while drilling a side of the tool also contributes to the machining process Hence taper is observed and side takes of parabolic profile since machining on the sides is for zero feed condition. One of the solutions is to provide side insulation
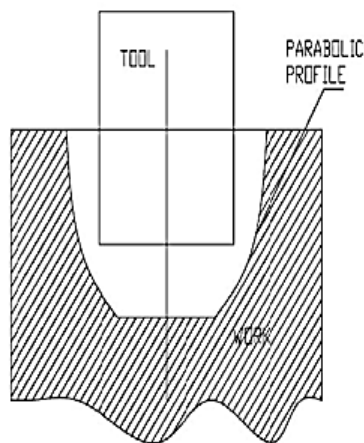

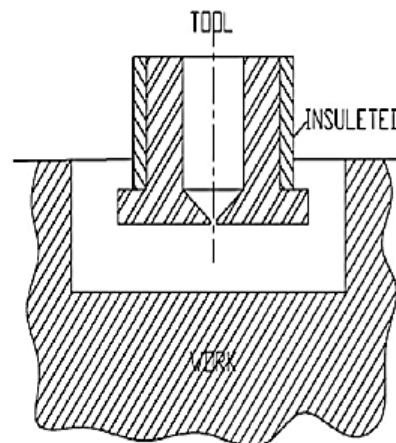Fig. 4
Machining with bare electrode [1]

Fig. 5
Machining with insulated electrode[1]

The initial side gap value will increase according to the forward motion of the electrode (tool). Each element of the tool electrode causes an increase in the work piece radius value equal to initial side gap, Y_{si}. Depending on the tool length (B) and the other working conditions of the ECM process, the work piece diameter (D_{wi}) will be determined according to the relationship.$D_{wi} = D_t + 2 Y_{si}$
Where D_t is the tool diameter
The electrolytic area (A) can be calculated as follows:

$A = \pi / 4 (D^2_{wi} - D^2_t)$
The electrolyte velocity (Vsi) can be calculated from the following equation:
Vsi = Q / Ai
Where Q is the electrolyte flow rate (mm3 / min)

The electrolyte velocity varies according to the change in the cross-sectional area of the flow. The metal removal thickness along the side gap can be computed as follows
$\Delta Y_{si} = ZJ_{si} \Delta t$

Where, Z is the effective metal removal rate (mm3 / min) and can be computed as follows : $Z = \varepsilon / \rho_w F$

Where ε is the chemical equivalent, ρ_w is the work piece density (g / cm3) and F is the Faraday's constant.

The current density at the work piece surface J $_{si}$ at the initial side gap value Y_{si} is commonly expected as follows:
$J_{si} = [V- \Delta V] K_i / Y_{si}$

Where K_i is the electrolyte conductivity and Y_{si} is the side gap, ΔV is the applied voltage and V is the over potential value.The successive machining time interval (Δt) can be estimated from the tool land interval (Δb) and the feed rate (f) according to this equation:
$\Delta t = \Delta b /f$
The width of the side gap at the end of b tool element length can be expressed as follows:
Ysi+1 = Ysi + Δ Ysi
Where ΔY_{si} is the metal removal thickness for tool element length b at side gap $Y_{si.}$

It has so far been assumed that the process of ECM to be of ideal in nature i.e the theory Involved considers electric field solely within the limits of of the gap assumes that it obeys ohm's law and faraday's law.With the flow of the electrolyte and machining at the highest feed-rate conditions.

,the work surface does not copy the replica of the tool the errors in machining are observed because:

- ➤ The electrolyte is heated up as it moves past the working gap and the temperature effect on the specific resistance of electrolyte reflects on the machining at any time.
- ➤ Flow of the electrolyte causes the reaction products at the cathode (gas bubbles to move along affecting the change in the resistance of the electrolyte
- ➤ Flow of the electrolyte once again causes the reaction products produced at the work surface (sludge and wear debris) to flow along to affect the change in resistance of electrolyte
- ➤ Gap length along the curved surface changes, since the feed is given in particular direction.

Aspect of tool design are

- ➤ Determining the tool shape so that the desired shape of the job is achieved for the given machined conditions.
- ➤ Designing the tool for electrolyte flow, insulation, strength and fixing arrangement

Theoretical determination of tool shape

When the desired shape of the machined workpiece surface is known , it is possible to theoretically determine the required geometry of the tool surface for given set of machining conditions.

Let the applied potential, the overvoltage, and the feed rate be V, V and f, respectively. The equilibrium gap between the anode and the cathode surfaces can be expressed as

ge = kA(V- Δ V)/ ρZF f cosθ

The coordinates x and y are selected so that the y axis and the feed direction are parallel. Let us consider two dimensional case, where there is no variation in z- direction. The work surface geometry is prescribed to be y = Φ(x)
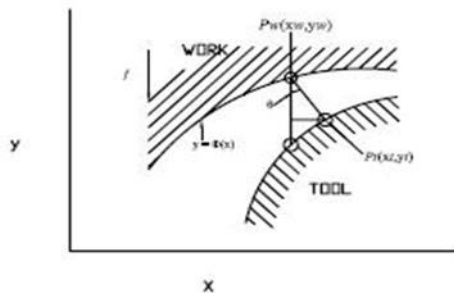

Fig 6. Generation of tool surface for given work surface[1]

As shown in fig.6 when the study state is reached, any point Pw(xw,yw) on the work surface can be transformed into the corresponding point Pt(xt,yt) on the tool surface so that Pw – Pt = ge.

Then,

$y_w - y_t = PwPt \cos θ = ge \cos θ$
$x_t - x_w = PwPt \sin θ = ge \sin θ$

$$d\Phi (x_w)/ dx_w = \frac{(b+2cx_t)/(1+2c(\lambda/f))}{} = \Psi(xt , yt)$$

for example , if the equation representing the work surface is $y_w = a + bx_w + cx_w^2$

then

$d\Phi (x_w)/ dx_w = b + 2 c x_w$

using equations (4.2) in this equation ,we get
$d\Phi (x_w)/ dxw = b + 2 c[xt - (\lambda / f) d\Phi (x_w)/ dx_w]$

Substituting the forgoing expression of Ψ (xt, yt) in equation ,we find that the required tool surface geometry becomes

$$y = a + b\left[x - (\lambda / f)((b+2cx)/1+2c(\lambda / f))\right]$$

$$-(\lambda / f) - c\left[x - (\lambda / f)((b+2cx)/1+2c(\lambda / f))\right]^2$$

Design for electrolyte flow

A sufficient electrolyte flow between the tool and the work piece is necessary to carry away the heat and the products of the machining and to assist the machining process at the required feed rate , producing a satisfactory surface finish . Cavitations, stagnation and vortex formation should be avoided since these leads to a bad surface finish.

One basic rule is that there should be no sharp corners in the flow path . All corners in the flow path should have a radius of at least 0.7 to 0 .8 mm shown in fig 7.
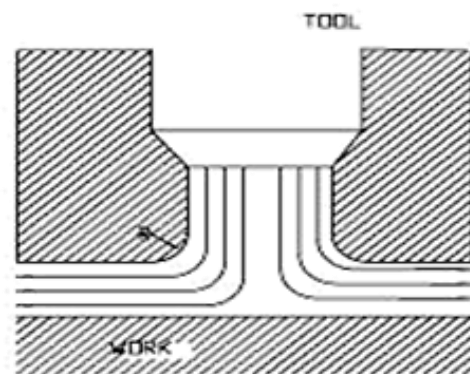

Fig 7. Avoiding sharp corners in tool path[1]

The initial shape of the component generally does not comply with the tool shape and only a small fraction of area is close to the tool surface at the beginning. When the I initial work shape conforms to the tool shape , the machining process itself causes the formation of boss or ridge in the workpiece , this helps in a proper distribution of the electrolyte flow.

Characterization

Drilling was characterized with the following parameters

1. *Hole profile,* that is variation of hole diameter with depth.
2. *Radial overcut,* defined as the difference between the largest hole radius (r_h) and cathode tool radius (r_r), i.e. $O_r = r_h - r_r$

IV STEPS TO FIND THE TOOL DIMENSION

1 Find out the work surface equation using second order equation which is made by existing tool
2. Find the tool surface equation using equation
3. Find out the overcut and reduce it from calculated tool equation
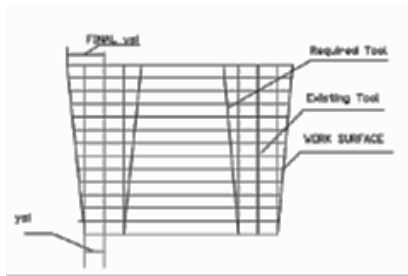4. Find out the regression equation
5. Find the tool dimension

Fig. 8 Relation of Required Tool against Existing tool

V RESULTS AND DISCUSSION

Result obtained through experiments on workpiece by Tool 1 shown in below table.

Fig. 9 Tool-1
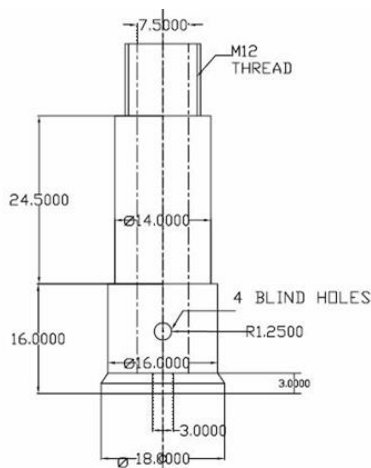
Fig. 10 Voltage vs Time against Tool-1

Table. 3 Experimental parameters with Tool -1

Experiment number	1	2	3	4
Tool used	1	1	1	1
Feed	0.32	0.54	0.97	1.13
Gap	0.6	0.6	0.6	0.6
Voltage	10	10	10	10
Dtop	21.60	22	22.3	22.42
Dbottom	19.97	20.30	20.50	20.80
Overcut	2.6	3	4.3	4.42

Fig. 11 Current vs Time against Tool-1
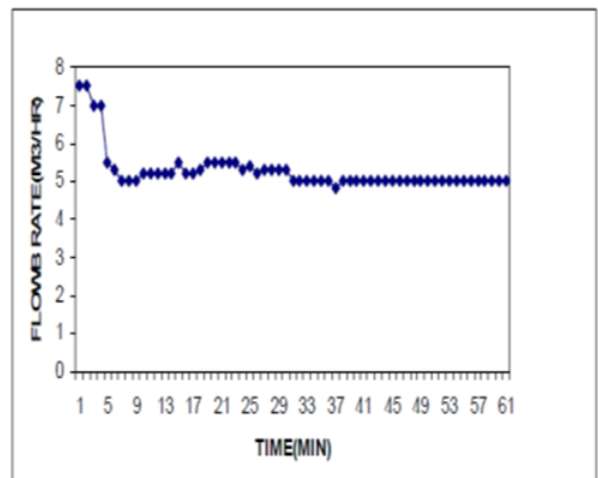
Fig. 12 Flow Rate vs Time against Tool-1

Theoretical calculation for over cut

Table. 4 ysi calculation with Tool -1

y	ysi	z	jsi	t	ysi	ysi1 =ysi + ysi
0	0.985	$3.69*10^{-5}$	0.88	187.5	0.006	0.991
1	0.991	$3.69*10^{-5}$	0.87	375	0.012	1.003
2	1.003	$3.69*10^{-5}$	0.86	562.5	0.017	1.02
3	1.02	$3.69*10^{-5}$	0.85	750	0.02	1.04
4	2.04	$3.69*10^{-5}$	0.45	937.5	0.015	1.055
5	2.055	$3.69*10^{-5}$	0.43	1125	0.018	1.073
6	2.073	$3.69*10^{-5}$	0.43	1312.5	0.02	1.093
7	2.093	$3.69*10^{-5}$	0.42	1500	0.03	1.116
8	2.116	$3.69*10^{-5}$	0.42	1687.5	0.026	1.142
9	2.142	$3.69*10^{-5}$	0.41	1875	0.028	1.17
10	2.17	$3.69*10^{-5}$	0.41	2062.5	0.031	1.201
11	2.201	$3.69*10^{-5}$	0.4	2250	0.033	1.234
12	2.234	$3.69*10^{-5}$	0.39	2437.5	0.035	1.269
13	2.269	$3.69*10^{-5}$	0.39	2625	0.038	1.307
14	2.307	$3.69*10^{-5}$	0.38	2812.5	0.04	1.347
15	2.347	$3.69*10^{-5}$	0.38	3000	0.041	1.388
16	2.388	$3.69*10^{-5}$	0.37	3187.5	0.043	1.431
17	2.431	$3.69*10^{-5}$	0.36	3375	0.045	1.467

Ysi   = (bottom work dia. - tool dia) / 2

     =   (19.97-18)/2

     =   0.985
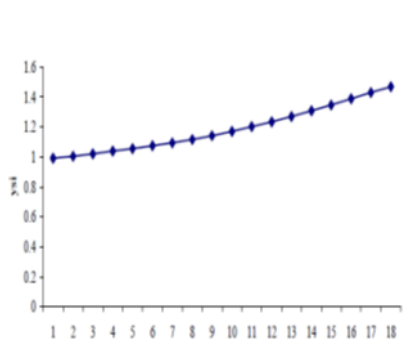
Fig. 13 Depth -to ysi relation

Fig. 14 Overcut vs feed for Tool-1

From the above tool equation, the new tool obtained is shown in below in fig. In order to reduce the overcut a modification has been done in the tool design, considering i.e. a taper has been provided and diameter made less(< 1.2) than required be made . So that the tool surface gap increases incrementally with depth, which intern decreases the current density, so that the overcut decreases.
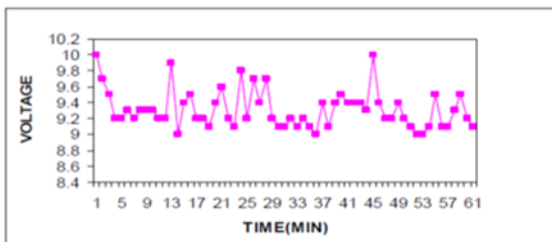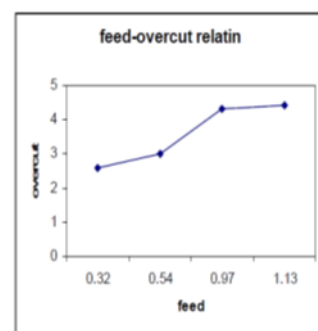
Table. 5 Experimental parameters with Tool -2

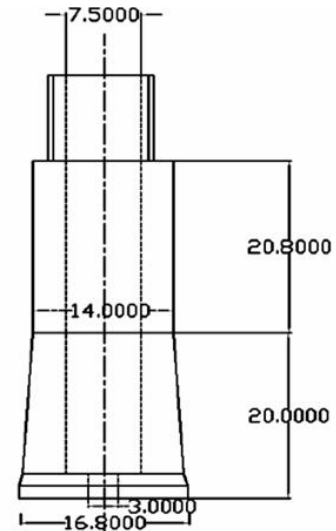| Experiment number	1	2
Tool used	2	2
Feed	0.32	0.32
Gap	0.2	0.6
Voltage	10	10
Dtop	20.4	21.4
Dbottom	18.4	18.9
Overcut	2.4	3.4

Fig. 15 Tool -2

Theoretical calculation for overcut Tool-2

Table.6 ysi calculation with Tool -2

y	ysi	z	jsi	t	ysi	ysi1 =ysi + ysi
0	0.95	$3.69*10^{-5}$	0.91	187.5	0.006	0.956
1	1.956	$3.69*10^{-5}$	0.44	375	0.006	0.962
2	2.012	$3.69*10^{-5}$	0.43	562.5	0.008	0.97
3	2.06	$3.69*10^{-5}$	0.42	750	0.01	0.98
4	2.13	$3.69*10^{-5}$	0.4	937.5	0.014	0.994
5	2.18	$3.69*10^{-5}$	0.39	1125	0.016	1.01
6	2.24	$3.69*10^{-5}$	0.38	1312.5	0.018	1.028
7	2.32	$3.69*10^{-5}$	0.37	1500	0.02	1.048
8	2.378	$3.69*10^{-5}$	0.36	1687.5	0.022	1.07
9	2.45	$3.69*10^{-5}$	0.35	1875	0.024	1.094
10	2.514	$3.69*10^{-5}$	0.34	2062.5	0.026	1.12
11	2.6	$3.69*10^{-5}$	0.33	2250	0.028	1.148
12	2.678	$3.69*10^{-5}$	0.32	2437.5	0.029	1.177
13	2.747	$3.69*10^{-5}$	0.31	2625	0.03	1.207
14	2.827	$3.69*10^{-5}$	0.3	2812.5	0.031	1.238
15	2.91	$3.69*10^{-5}$	0.29	3000	0.032	1.27
16	2.99	$3.69*10^{-5}$	0.29	3187.5	0.034	1.304

From the tool two we got bottom part nearer to 18 which we required but overall overcut is nearly remain same in order to control Dtop The tool has been further modified, to get uniform diameter, of the above modified tool, deducting the

overcut value from the tool surface, and regression eqn has been found to be $x = 21.44 + 0.096y$.

The Ysf value obtained from the above calculations is 1.304.in this calcaculation of ysi is increased due to taper shape

The total overcut = 2 * Ysf -1.2

$\qquad$ =2 * 1.304 -1.2

$\qquad$ =   1.408

Table. 7 Experimental parameters with Tool -3

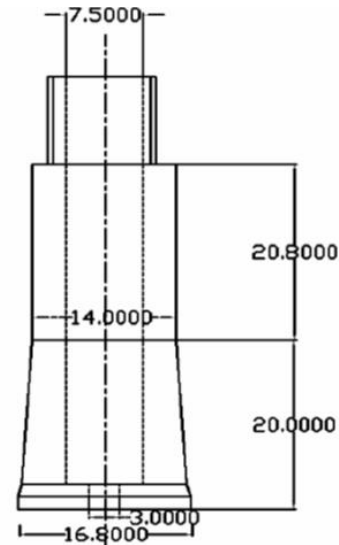| Experiment number	1	2
Tool used	3	3
Feed	0.32	0.32
Gap	0.2	0.6
Voltage	10	10
Dtop	18.2	18
Dbottom	17.4	17.2
Overcut	0.2	0

Fig 16. Tool 3

Theoretical calculation for overcut Tool-3.

Table. 8 ysi calculation with Tool -3

y	ysi	z	jsi	t	ysi	ysi1 =ysi + ysi
0	1	$3.69*10^{-5}$	0.87	187.5	0.006	1.006
1	1.131	$3.69*10^{-5}$	0.77	375	0.01	1.141
2	1.266	$3.69*10^{-5}$	0.62	562.5	0.014	1.28
3	1.405	$3.69*10^{-5}$	0.49	750	0.017	1.422
4	1.547	$3.69*10^{-5}$	0.38	937.5	0.019	1.566
5	1.691	$3.69*10^{-5}$	0.29	1125	0.021	1.712
6	1.837	$3.69*10^{-5}$	0.24	1312.5	0.023	1.86
7	1.985	$3.69*10^{-5}$	0.19	1500	0.024	2.01
8	2.134	$3.69*10^{-5}$	0.155	1687.5	0.025	2.159
9	2.284	$3.69*10^{-5}$	0.129	1875	0.026	2.31
10	2.435	$3.69*10^{-5}$	0.109	2062.5	0.027	2.432
11	2.587	$3.69*10^{-5}$	0.092	2250	0.028	2.615
12	2.74	$3.69*10^{-5}$	0.08	2437.5	0.0285	2.768
13	2.893	$3.69*10^{-5}$	0.069	2625	0.029	2.922
14	3.04	$3.69*10^{-5}$	0.061	2812.5	0.0296	3.069
15	3.194	$3.69*10^{-5}$	0.053	3000	0.03	3.225
16	3.35	$3.69*10^{-5}$	0.048	3187.5	0.03	3.38

The total overcut = 2 * Ysf - 2

The Ysf value obtained from the above calculations is 3.38

= 2 * 3.38 -2
= 4.76

Though theoretically it is more value but experimentally overcut is only 0.2 but the problem occurred with this tool is hole diameter became less than 18 .that is upto 17.2.

Step-1

Tool surface equation is $Y = a + bx + cx^2$

Using above three values of x and y we can find out the work surface equation. The work surface equation is

$y = -1523.62 + 135.77 \, x - 3.02 \, x^2$

Step-2

The tool equation is

$$y = a + b\left[x - (\lambda / f)((b + 2cx)/1 + 2c(\lambda / f))\right] - (\lambda / f) - c\left[x - (\lambda / f)((b + 2cx)/1 + 2c(\lambda / f))\right]^2$$

$$ge = \lambda / f = ka(v - \Delta v)\rho z f \cos\theta$$

Putting values of a,b ,c we get tool equation

$y = -0.48 \, x^2 + 21.2 \, x + 228$

Step3

Ysi calculation

From the experiment at the bottom $(19.97-18) / 2 = 1$ mm

Step 4

Line of regression for curve fitting

Table. 9 Calculations

Y	X	x-2ysi		Y	x	x-2ysi
0	18.52	16.53		10	16.2	13.38
1	18.2	16.16		11	16.1	13.18
2	17.9	15.8		12	15.9	12.87
3	17.7	15.5		13	15.7	12.57
4	17.5	15.2		14	15.6	12.33
5	17.2	14.84		15	15.4	12
6	17	14.57		16	15.3	11.74
7	16.8	14.26		17	15.1	11.38
8	16.6	13.97		18	15	11.28
9	16.4	13.67		avg	13.74	

x = a + by
$\sum$ x = n*a + b $\sum$ y
$\sum$ x*y = a $\sum$ y + b $\sum$ y^2
b= ($\sum$(x − x avg) * (y − y avg) / ($\sum$ (y − y avg)^2)

b= - 169 / 570 ,b= -0.29

Régression equation

(x - x avg) = b * (y − y avg)
(x-13.74) =-0.29 (y − 9)
x -13.74 = -0.29 + 2.61y x + 0.29 y = 16.35
y = 16.35

Step 5

The final dimensions of tool are shown in table no10

Table. 10 final dimensions of Tool

Y	X	y	x
0	16.35	10	13.45
1	16.06	11	13.16
2	15.77	12	12.87
3	15.48	13	12.58
4	15.19	14	12.29
5	14.9	15	12
6	14.61	16	11.71
7	14.32	17	11.42
8	14.03	18	11.13
9	13.74	19	10.84
		20	10.55

Notations

Y_{si}-- Initial side gap
B--Tool length
D_{wi}--Work piece diameter
D_t -- the tool diameter.
Vsi -Electrolyte velocity
Q - The electrolyte flow rate
Z - The effective metal removal rate
E - The chemical equivalent,
P_w - The work piece density
F - The Faraday's constant
J_{si} -The current density at the work piece surface
K_i - the electrolyte conductivity ,
Δ V - the applied voltage
V - the over potential value.
Δ t -The successive machining time interval
Δ b- Tool land interval
f-The feed rate

VI CONCLUSIONS

Overcut is directly proportional to current density and feed rate. Taper tool gives less overcut than step tool. Diameter of tool should be less than required hole. When initial gap between workpiece and tool is more results in larger overcut.

Overcut is directly proportional to current density and feed rate. Taper tool gives less overcut than step tool. Diameter of tool should be less than required hole. When initial gap between workpiece and tool is more results in larger overcut.

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