Optimization of WEDM Parameters for circular profile cuts during machining of Al-7075 Alloy

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Abstract : This Research paper proposes optimal process parameters for Aluminium-7075 alloy metal on Wire cut Electrical discharge machine(WEDM). Aluminum alloys used for aeronautical applications are machined by using WEDM to obtain minimum taperness. A series of experiments are developed to investigate the effect of machining parameters such as Pulse on Time (T_{ON}), Pulse off Time(T_{OFF}),Wire Feed Rate(WFR) and Control of Speed(COS) on Taperness, DimensionalDeviation(DD), Wire Wear Rate(WWR) and Metal Removal Rate(MRR). Al-7075 alloy is machined intothe Circular profile geometries.Optimization of process parameters is performed by using a Genetic Algorithm technique which is most powerful unconventional robust tool. A mathematical model was developed using regression equation. Finally, comparisondonebetween experimental values and optimum values to obtain conformation, level greater than 95%. The optimum range of machining parameters to produce a quality cut the optimum responses identified for circular geometrythe identifications are Pulse on Time-103, Pulse off Time-59.99,Wire Feed Rate-2.0497 mm/min and Control of Speed-71.2864% for optimum response.

Keywords: **WEDM, Genetic algorithm, Taperness, Al-7075 alloy, Wire Wear Rate, Dimensional Deviation and Regressionequation.**

I. INTRODUCTION

Wire cut Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate an electrical spark. Material removal mainly occurs due to the thermal energy of the spark.

WEDM is mainly used to machine difficult-to-machine materials and high strength,temperature resistant alloys. WEDM can be used to machine difficult geometries in small batches or even on the job-shop basis. Work materialto be machined by WEDM has to be electrically conductive.

In this process the metal removing from the work piece due to erosion is caused by rapidly recurring spark discharge taking place between the tool and work piece. In Fig.3 represents the mechanical set up and electrical set up and electrical circuit for electro discharge machining,a thin gap about 0.025mm is maintained between the tool and work piece by a servo system

The copper wire is working as cathode, generally copper, brass, molybdenum and tungsten wire with diameter of 0.25 mm is considered and the work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of 10 microseconds.

Positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values, producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached. At such high pressure and temperature, some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Materialremoval occurs due to instant vaporization of the material as well as due to melting.In WEDM, the machining of the work piece is carried out in a dielectric fluid. It is ionized water(conducting electricity) in order to make environment friendly. Lubricants will generate toxic flames during machining and it makes hazards.Design of Experiment is one of the optimized tools utilized to achieve maximum information from the least amount of resources [1]. WEDM process can successfully machine the hard and difficult to machine materials like Composites [2]. The control factors Pulse on Time has been found to be a major factor affecting the MRR[3-4].Higher value of T_{OFF}improves quality of surface [5].Regression equation measures the impact of input on output [6].By using regression equation mathematical models have been developed to formulate and investigate the effects of process prameters onprocess responses [7].In Multiobjective optimization function has been transferred in to single objective function [8].To convert the minimum objective into maximization, it was suitably modified [9]. In this work effect of process parameters such as T_{ON}, T_{OFF},WFR and COS are investigated on process responses such as Taperness,MRR,Wire wear rate and DD. The holetapersdetermine the quality of machining. Finding of holetaperness and its importance has not discussed by any researcher in the case of WEDM.

II. EXPERIMENTAL SETUP

2.1. Material

Generally Al-7075 (Al-mg-si) alloy which is shown in Fig.1contains relatively high strength, good workabilityformability, bending properties, high resistence to corrosion, excellent joining characterstics,widely available. The Al-7075 has extreme scopeof applications such as heavy-duty structures, Aircraft fittings, couplings and marine fittings.

Table 1 Chemical composition of Al-7075 alloy

S.No	Al	Si	Fe	Cu	Mn	Cr	Zn	Ti
1.	90.03	0.052	0.2	1.4	0.05	0.19	5.9	0.047

Fig.1 Aluminium-7075 alloy specimen.

2.2. Methodology

The objective of this research work, is to investigate experimentally Wire cut electrical discharge machining of Al-7075 alloy.The Taguchi method used to design the experiments and collected process responses data analysis is carried out by using Genetic Algorithm.The experimentation was carried out based on L_{16} orthogonal array forcircular geometries and process responses are listed as shown in Table 3.

The novelty in this work is that we performed WEDM Machining on Aluminium-7075 alloy. T_{ON}, T_{OFF},Wire Feed Rate(WFR) and Control of Speed(COS)which are very important for optimizing Inflation of quality of cut in WEDM is depends up on process parameters. For this reason, the experimentation based on orthogonal array L_{16} is carried out on Aluminium-7075 alloyfor investigating the effect of various WEDM machining parameters. Genetic algorithm is perfomed to evaluate the optimum process parameters as well as the most significant parameters affecting the machining performance.

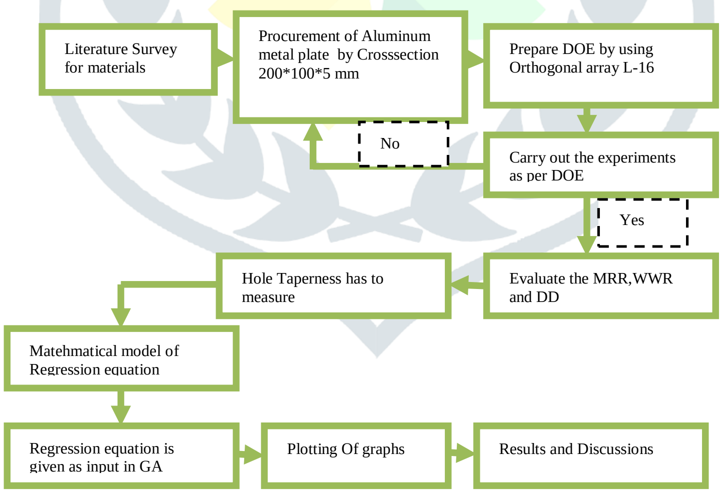

Fig .2Flow chart of the proposed Methodology

2.3. Preparation of Specimens

Aluminium-7075 alloy workpiece 200*100*5 mm^3 work piece is used for machining 16 précised holes for circular geometry 10*10 mm^2 and circular geometry of diameter 10mm separately.

2.4. Preparation of Machine setup:

Fig.3 WEDM Machine setup with CNC.

The experimentation wascarried out on WEDM as in above Fig.3.circular specimens were machined on Aluminium-7075 alloy blank. Dielectric fluid is taken for lubrication.With the help of fixture workpiece was clamped to worktable. A reference point was consider on the workpiece for setting Work Coordinate system (WCS). The machining of WEDM was perform by controlling the machining with computer.First designing of machining profile is done by using RRCADD software then drawing file is uploaded in to egen software and then machining was performed on WEDM.The WEDM system used for this research had a copper wire with diameter of 0.25 mm having electricity conductor nature is used as electrode.Total 16 circular geometry experimental runs were carried out on a WEDM setup available at Vellore Wire cut industry-Vellore,Tamil Nadu, India.

2.5. Parameter Setting:

1. ***Pulse on Time(T_{ON})***: The duration time of spark measured.
2. ***Pulse off Time(T_{OFF})***: The time lag between sparks.
3. ***Wire Feed Rate(WFR):*** The speed at which wire is Feeding-mm/min.
4. ***Control of speed (COS):*** The speed with which machine speed is controlled.

Table 2 Process parameters and their levels

SI.No	Parameter	Level			
		I	II	III	IV
1.	Pulseon Time- µs	103	105	107	109
2.	PulseoffTime- µs	56	58	60	62
3.	Wire feed rate- mm/min	2	4	6	8
4.	Control of speed- %	40	60	80	100

Table.2 contains the details of various experimental runs conducted.

2.5. Selection of Orthogonal Array:

In Taguchi method Control factors refers to input parameters for the process, and Response factors refers to corresponding output parameters for the process.

Orthogonal Array = (No. of Parameters +1) × (No. of Levels in 'B' - 1) = 5 * 3 =15.

The nearest OA available for satisfying the above condition of selecting OA is L_{16}.

Table 3 Experimental Trailsfor Circular geometry

S.No	T_{ON} µs	T_{OFF} µs	WFR mm/min	COS %	MRR gm/min	DD mm	WWR mm	Taperness radians
1	103	60	2	40	0.0121	0.158	0.008	0.071
2	103	58	4	60	0.0127	0.1595	0.005	0.044
3	103	56	6	80	0.0130	0.154	0.007	0.002
4	103	54	8	100	0.0126	0.153	0.008	0.001
5	105	60	4	80	0.0136	0.1585	0.006	0.001
6	105	58	2	100	0.0115	0.1545	0.007	0.005
7	105	56	8	40	0.0250	0.156	0.008	0.002
8	105	54	6	60	0.0250	0.1535	0.005	0.001
9	107	60	6	100	0.0286	0.1675	0.005	0.045
10	107	58	8	80	0.0274	0.169	0.006	0
11	107	56	2	60	0.0301	0.1695	0.004	0.001
12	107	54	4	40	0.0290	0.1755	0.008	0.007
13	109	60	8	60	0.0323	0.169	0.004	0.014
14	109	58	6	40	0.0309	0.1755	0.003	0.009
15	109	56	4	100	0.0270	0.162	0.006	0.002
16	109	54	2	80	0.0296	0.171	0.007	0.009

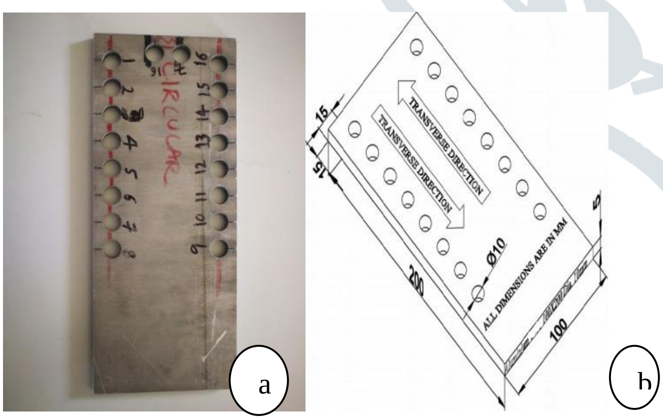

Fig. 4 a. Machined workpiece with circular profiles

b.Circular profile CAD model

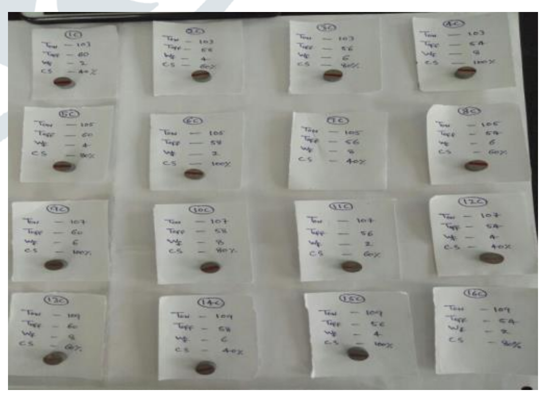

Fig.5Circular profile machined workpieces

2.6. Regression Equation:

The Regression equation is used to optimize the output parameters by using the formulae individually. The regression equation is used to calculate the best grade for all the individual parameters.It is used to get the best output value for all parameters by substituting the obtained values in the regression equations find from a analysis Software .

MRR= $_e$^(4.0)* (TN) ^(-1.34)* (TF) ^(-0.44)* (WF) ^ (0.0389)* (CS) ^(-0.057) (1)

WWR= $_e$^(35.2)* (TN) ^(-6.66)* (TF) ^(-2.37)* (WF)^(-0.078)* (CS)^(0.104) (2)

DD= $_e$^(-10.23)* (TN) ^(1.770)* (TF) ^(0.084)* (WF) ^(-0.0067)* (CS) ^(-0.0403) (3)

Taperness= $_e$^(-77.6)* (TN) ^(-1.9)*(TF) ^(21.32)* (WF)^(-0.291)* (CS)^(-1.098) (4)

2.7. Genetic Algorithm:

Genetic Algorithm proposed by J.H.Hollandis a stochastic search method that means the natural biological evolution.One generation of GA includes Reproduction, Crossover and Mutation. The particular GA can useto write the program for integer values and real variables.

2.7.1. Reproduction*:* Reproduction is the selection for copies of chromosome,according to the Fitness value.

2.7.2. Cross Over *:*Crossover produces new individual Exchange of portions between chromosomes by meansof any one of the following algorithm.

2.7.3.Mutation : Mutation means a sudden change ofParameter. It may help to overcome the local Minima problem.

1. An automatic search for the non-linear connection between the inputs and outputs.
2. Fast and simple optimizing technique.
3. Estimate the potential minimum value of the machining performance with the recommended Optimal process parameters.

In the GA based optimization module, the predicted equation of the regression model would define the optimization objective function. The minimum and maximum process parameter values of experimental design would define the optimization limitation constraints. Based on some criteria the minimum predicted performance value at the optimal solution was estimated as shown in fig.. GA is used to solve maximization problem.To solve minimization problem in GA it conflict into maximization problem.

Minimize y=f(x) can be write as maximize y=1/f(x) (5)

III. RESULTS AND DISCUSSION

3.1. Process Responses:

1. Metal Removal Rate(MRR)-gm/min=

$$\frac{\text{Amount of metalremoved from the workpiece(W)inmm}^3}{\text{time taken for machining(t) in min}} \quad (6)$$

2. Dimensional Deviation (DD)-mm:

$$\frac{\text{((Actual Dimension-Measured dimension)}}{2} \times 100 \quad (7)$$

3. Wire wear Rate(WWR)-mm:

Wire diameter before cut- Wire diameter after cut (8)

4. Taperness-radians: Hole taper (rad)= $\frac{\text{(Hole entrance diameter- Hole exit diameter)}}{\text{(2*thickness)}}$ (9)

Control of speed show its effect on taperness during machining of circular geometry ,a lot of care has to take during taperness and Dimensional Deviationhas to maintain at optimum range. Pulse on Time generates a lot of high discharge energy and spark. Pulse off Time represents no machining is happend because of no spark generation takes place. By reducing the wire feed rate and increasing the Pulse on Time wire wear rate increases.

The results plotted based on Genetic Algorithm is listed in below.

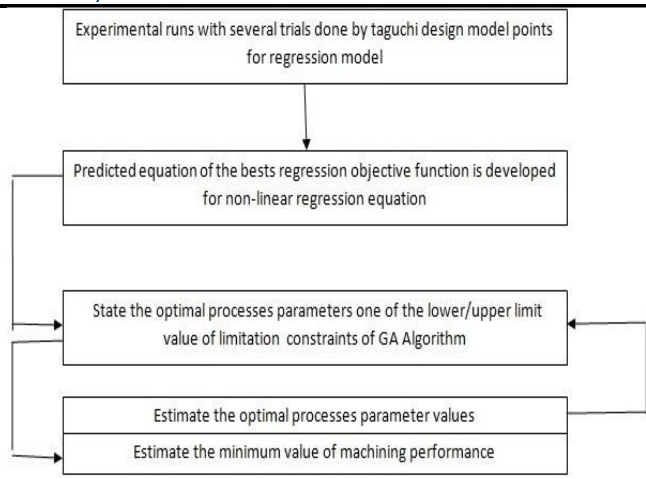

Fig.5 The flow of proposed Genetic Algorithm

3.2. Calculation of weights for Circlar Geometry:

Weights are found out by using entropy method.

Table 4 Weights for process responses

S.No	Parameter	Units	Circular
1	Taperness	radians	0.8428
2	MRR	gm/min	0.109
3	WWR	mm	0.0468
4	DD	mm	0.00081

3.3.TheFitness function for Circular Geometry:

Y=((0.109*(19930.3704)*(X)^-1.34*(Y)^(-0.44)*(Z)^0.0389*(r)^(-0.057)))+(0.001*(3.6072*10^(-5)*(X)^1.770*(Y)^0.084*(Z)^(-0.0067)*(r)^(-0.0403)))^-1)+(0.843*(1.9895*10^-34*(X)^(-1.9)*(Y)^21.32*(Z)^(-0.291)*(r)^(-1.098)))^-)+(0.047*(1.93716*10^(15)*(X)^(-6.66)*(Y)^-2.37*(Z)^(-0.078)*(r)^(0.104)))^-1 …. (10)

Simple fitness function=@simple_fitness;

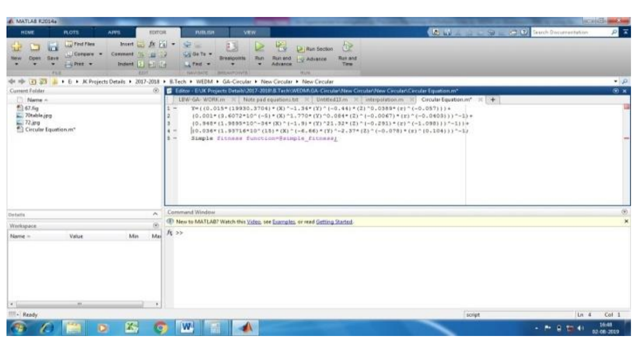

Fig.6 Assignment of Boundary conditions in GA Tool.

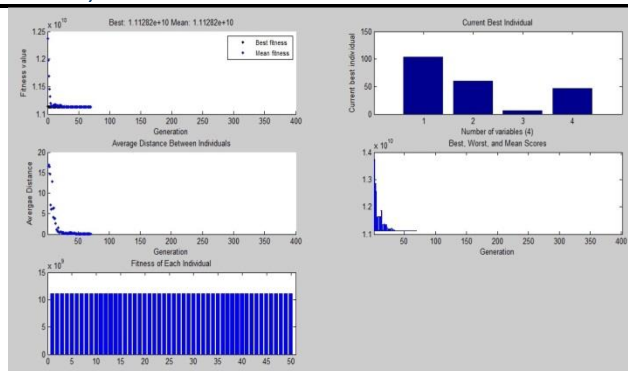

Fig.7 Best Fitness function graph for Circular geometry

Table 5 Optimal solution obtained by GA Combination

S.No	**Parameters**	**Setting value / Function type**
1	Population Size	100
2	Scaling Function	Rank
3	Selection Function	Rolette wheel
4	Cross over function	Heuristic
5	Crossover rate	0.8
6	Mutation function	Adaptive feasible

The best fitness improves slowly in a later generation, whose populations are closer to theoptimal global point, but 92^nd^iteration for circular geometry.

Table 6 Optimal process parameter obtained by Genetic Algorithm tool

S.No	**Geometry**	**TON µs**	**TOFF µs**	**WFR mm/min**	**COS %**
1.	Circular	103	60	2.0497	71.2864

From above Table 7 for circular geometries machined pieces has optimal values and experimental values % of error for MRR is 1.14%, WWR is 1.47%,Dimensional Deviation is 3.59% and Taperness is 3.20%for circular geometry and Control Of Speed is reduced by half of its speed in order to machine circular geometry.

To obtain optimum process responses optimum parameters which are shown in Table 6 are substituted in regression equations 1,2,3 and 4 hence we get optimum process responses as shown in below Table 7.

Table 7 Optimum parameter control level for Circular geometry

S.No	Geometry	Process Response	Experimental Value	Optima l Value	% of Error
1.	Circular	MRR-gm/min	0.0879	0.0869	1.14
2.		WWR-mm	0.00685	0.00675	1.47
3.		DD-mm	0.1557	0.1615	3.59
4.		Taperness-radians	0.0181	0.0187	3.20

From the conformation of experiments, the percentage of process responses from the predicted responses are less than 2% it is acceptable if error is less than 5% its conformation level is 98% of the bell curve.

3.4.Analysis of Variance:

Anova was performed to interpret the non-linear behavior of the processes parameters, on the process responses. In order to assess the contribution of each influencing process parameter on the optimization of process response.

Table 8 Analysis of Variance for multi objective optimum responses

Source	DOF	Adj SS	Adj MS	F-Value	Percentage Contribution Factor	Rank
T_{ON}	3	0.035	0.011787	1.28	27.62794	1
T_{OFF}	3	0.022	0.007353	0.80	17.23494	3
WFR	3	0.030	0.010221	1.11	23.95734	2
COS	3	0.012	0.004075	0.44	9.551527	4
Error	3	0.027	0.009229		21.63216	
Total	15	0.127				

IV. Conclusion

In this paper Wire cut Electrical Discharge Machining was used for machining of Al7075 -alloy. circular geometry were carried out to investigate the effects of process parameters (i.e., Pulse on Time, Pulse off time, Wire feed rate and Control of speed) on the quality of machined work pieces such as Metal Removal Rate(MRR), Dimensional Deviation(DD), Wire Wear Rate(WWR) and Taperness conclusions are drawn based on Genetic Algorithm Technique.

1. Four factor four level factorial design matrix could be effectively used for the development of mathematical model's regression equation.
2. The effect of Pulse on Time- T_{ON} is a most significant factor on Metal Removal rate. Pulse on Time generates a lot of high discharge energy and spark.
3. During Pulse off Time- T_{OFF} no machining is happend because of no spark takes place. Such that Pulse off Time has to reduce to improve Metal removal rate.
4. The Wire Feed Rate- WFR shows its effect on Wire wear rate. By reducing the wire feed rate and increasing the Pulse on Time wire wear rate increases.
5. The Control of speed-COS has an important effect on Taperness and Dimensional deviation it has to maintain at optimum range.
6. It can be inferred that optimized processes parameters for Circular geometry is COS- 71.2864%, T_{ON} -103, T_{OFF}-60, WFR-2.0497mm/min for attaining the better quality in

   Wire cut Electrical Discharge Machining processes for Al-6061.
7. The accuracy of the developed mathematical models was tested by conformity tests for the experiments and the optimal results show that the accuracy of all the models were around 96%.

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