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Analysis of the Effect of Machining Parameters on Wire Electrical Discharge Turning of Stainless Steel

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ABSTRACT

Using wire EDM technology (WEDM), hard to machine and electrically conductive components are machined. Similarly cylindrical wire electrical discharge turning (CWEDT) process was developed to generate precise cylindrical forms on hard to machine materials. A precise, well designed set up was developed and added to CNC WEDM machine. This setup was required to hold the work-piece and impart rotary motion to it. This paper mainly investigates on the effects of machining parameters on MRR and surface roughness in cylindrical wire electrical discharge turning (CWEDT) process. In this research stainless steel of grade (316) was used in the experiments because of its growing applications in the field of manufacturing in the cylindrical forms. The machining parameters such as rotational speed, pulse off time, pulse-on time, wire feed and spark gap have been analysed using Taguchi method.

Keywords - Wire EDM turning; Taguchi method; Material removal rate; Surface roughness; Stainless steel (SS316).

1. INTRODUCTION

The lathe machine, drilling machine, slotting machine and various others have been traditionally been used for machining. As the applications in the industry advanced, the need to develop better processes for machining developed. Sometimes, it was required to cut very hard materials, which was not feasible using the conventional processes of machining. Problems such as tool wear, recast layer, bad surface finish, roundness error, machining of delicate components and so on also needed to be tackled. Hence “Advanced machining processes” or “unconventional machining processes” have emerged. These processes have the advantage that they do not require contact between tool and work piece. This was contrary to the case in conventional machining where the tool should always be harder than the work piece.

Work piece hardness is irrelevant in advanced machining processes. Advantages such as better surface finish, ability to machine delicate components, making intricate shapes in hard to cut materials, high material removal rate (MRR), batch production of components and many others made these processes very attractive and sought after in many large scale industries. Examples of such processes are Electrical Discharge Machining (EDM), Wire-EDM, Chemical Machining, Electro-Chemical machining, Abrasive jet machining (AJM), Water jet machining (WJM), Abrasive water-jet machining (AWJM), Electron beam machining (EBM), Laser beam machining (LBM) and many others.

One of the unconventional processes commonly used in industries is Electrical Discharge Machining (EDM). It uses a tool electrode connected to the positive terminal and the work piece connected to the negative terminal. The gap is filled by a dielectric fluid (kerosene, paraffin oil, lubricating oil, transformer oil). A high voltage (~20-150V) is applied to the electrodes. Since the dielectric material separates the gap, current is not able to pass through. As the dipoles align themselves in the direction of electric field, concentration of charges at particular regions take place.

When the threshold voltage is reached, a high intensity spark is produced for a short duration which erodes the work piece material as well as the tool material (very less erosion compared to work piece) due to high amount of heat energy produced. The dielectric fluid ensures the concentration of charges to a small region. The dielectric fluid is circulated through the work piece- tool gap which carries away the wear debris and also cools the tool. The circulated fluid is filtered and supplied again to the gap. This process can be used to machine any component provided it is conductive. The surface finish produced is very high (~0.18-0.25μm). EDM is used in aerospace applications, fabrication of press tools and mainly in die sinking processes. However this process gives matte finish, hard recast layer and heat affected zone (HAZ).

Wire EDM is a process which uses a thin metallic wire as tool which traverses over the work material to produce the desired profile or shape. During the entire process, it keeps on supplying fresh wire. The dielectric used in this case is deionized water, as it has high thermal conductivity to carry off large amounts of heat generated in the work- tool interface, provides higher cooling rate and thin recast layer. It is commonly used in fabricating extrusion dies. A CNC wire positioning system is commonly employed to control the wire movement. The main advantage of this process is that it can be used to make intricate shapes in delicate as well as hard materials such as Titanium and its alloys.

During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work-piece and the wire, eliminating the mechanical stresses during machining. The hardness and strength of the difficult to machine work material are no longer the dominating factors that affect the tool wear and hinder the machining process. This makes the WEDM process particularly suitable for machining hard, difficult to machine materials. In addition, the cutting force in WEDM process is small, which makes it ideal for fabricating small parts.

However it is known that materials like titanium and its alloys are frequently used in many applications. An example is titanium grade5 (Ti6Al4V) which is commonly used in aerospace, medical, marine industries as well as in chemical processing. Therefore, basic operations 3

such as turning, shaping, knurling, boring and so on are required in many industries.

Wire EDM turning (WEDT) is a process which uses the wire in WEDM to turn the work piece and thus achieve the required dimensions. Although many experiments have been carried out in this field, it still suffers the drawbacks of low MRR.

The idea of using wire EDM to machine cylindrical parts for manufacturing small pins had been reported by Masuzawa et al. [1] which were used as tools for 3D micro-EDM application (Rajurkar and yu [2]) and in water cooled submerged spindles extending the application of WEDM to cylindrical WEDM turning with rotation speed up to 2800rpm. This enabled the production of gear wheels with integrated shafts for easy gear assembly. Masuzawa et al, Qu et al [3] derived a mathematical model for material removal rate (MRR) of CWEDT process. He also investigated the surface integrity and roundness of CWEDT parts using brass and carbide work material. Mohammadi et al [4] investigated the turning by wire electric discharge machining to evaluate the effects of machining parameters on MRR, surface roughness and roundness by Taguchi approach. Janardhan and Samuel [5] used pulse train data analysis to investigate the effects of machining parameters on performance of wire electrical discharge turning process (WEDT). Regarding design Scott et al [6] used a factorial design requiring a number of experiments to determine the most favorable combination of the WEDM parameters. They found that the discharge current, pulse duration and pulse frequency are the significant control factors affecting the MRR and surface finish, while the wire speed, wire tension and dielectric flow rate have the least affect. An experimental study to determine the MRR and surface finish for varying machining parameters has also been conducted Rajurkar and Wang [7].The results have been used by presenting a thermal model to analyse the wire breakage phenomena. Liao et al. [8] proposed an approach of determining the parameter settings based on Taguchi quality design and analysis of variance. Huang and Liao [9] presented the use of grey relational and S/N ratio analysis, which showed that MRR and surface finish are easily influenced by the table feed rate and pulse on time. The electrode wear ratio and material removal rate optimization method using Taguchi's method was proposed for wire EDM operation by George et al. [10].

2. EXPERIMENTAL PROCEDURE

2.1 Development of Setup

The setup acts as a work holding device and supports the rotating work piece. It is connected to the wire EDM machine. The positive and negative terminals are connected with help of clamps.

The main components of the setup are as follows:

- Motor provides rotational power to hollow shaft.
- Belt transmits rotational power to work piece.
- Hollow shaft transmits rotation to the work-piece.
- Pulley transmits power to the hollow shaft.
- Carbon Brush conducts current to the rotating work-piece.
- Clamp holds and reduces the vibration of the motor in the setup.

The purpose of spindle is to give rotary motion to the work-piece during discharge. Precision spindle is the key sub-system for cylindrical wire electro-discharge turning process.

The basic requirements for the setup are:

- Protection from dielectric fluid during flushing.
- Provision of zero potential (grounding) to the circuit.
- It should spin in perfect rotational motion.
- Proper electrical insulation should be provided to the bearings to protect them from wear due to high amount of electrical discharges in the presence of water.

2.2 Description of experimental setup

The experimental setup for conducting WEDT experiments is shown in Fig. 1. The experiments are conducted on ELECTRONICA ECOCUT WEDM machine. The setup was prepared and attached to the wire EDM machine by bolting it to its workspace. The motor is connected to the DC supply which is changed to get different rotational speeds. By using an electrical clamp, the brushes and hence work piece is given a negative potential and the brass wire is connected to the positive terminal. Deionized water forms an envelope around the wire. The water flow is maintained throughout the procedure. The pressure of water is maintained at a constant value of 4x105 N/m^2.

Fig. 1 Raw material (SS 316 grade)

The work material used in this experiment is stainless steel (SS316 grade). This material is frequently used for numerous applications as it is corrosion resistant and has sufficient hardness for high load applications.SS316 grade is the commonly used form of stainless steel. This has a Brinell hardness of 123BH. The machining length on the work piece for the experiment is kept as 8mm.

A brass wire of 0.25 mm diameter has been used. This choice is made as in brass wire wear is less and it is cheaply available. Deionized water is used as a dielectric as it can conduct vast amounts of heat generated in the process. Also, water has a high dielectric constant, enabling it to provide high concentration of sparks along the curved surface of the wire.

In general, the process variables are the rotational speed, pulse off time, pulse on-time, power, voltage, spark gap, servo feed and flushing pressure. In the present experiment, the effect of rotational speed, pulse off time, pulse on time, wire feed and spark gap are analysed to determine their impact on MRR and surface roughness.

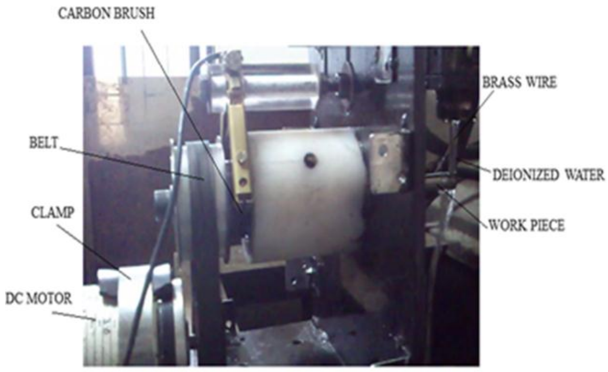

Fig. 2 Experimental setup

2.3 Description of components

Work piece material: The work material use in this experiment is stainless steel (SS316 grade). This has a Brinell hardness of 149BHN. The machining length on the work piece is kept as 10mm. The dimensions of the cylindrical work piece: 10mmx60mm.

Wire material: A brass wire of 0.25 mm diameter is used in the experiment. This choice is made as in brass wire wear is less and it is cheaply available.

Dielectric: Deionized water is used as a dielectric as it can conduct vast amounts of heat generated in the process. Dielectric is essential because it provides a medium for spark to concentrate and thus erode the material.

2.4 Design of experiment based on Taguchi method

Design of experiments (DOE) is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statics, these terms are usually used for controlled experiments. Formal planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components, and materials.

The method used for determining the effect of various parameters on MRR was Taguchi method. This is actually a part of design of experiments (DOE) by which we can determine the relations between parameters. By considering five parameters and each parameter having three values, then a total of 343 experiments will have to be performed. However, by Taguchi method, it is possible to determine the relations by just doing 27 experiments (L27 method).

By using the Minitab software, the Taguchi design was created. The motor speed was first set to 200rpm (this being the minimum speed of the motor). For this speed, progressive values of spark gap and pulse off time were recorded. Similarly, the same procedure was followed for rotational speeds of 350 rpm and 500 rpm.

Table 1 Factors and Factors levels

PARAMETERS	LEVEL 1	LEVEL2	LEVEL 3
Gap VOLTAGE (V)	30	45	60
Pulse on time (µs)	2	5	8
Pulse off time (µs)	2	4	6
WIRE SPEED(m/Min)	2	4	6
Rotational speed (rpm)	200	350	500

Table 2 Observations of all 27 experiments according to Taguchi design

EXP.NO	V	Ton	T-off	N	RPM	(Ra)	MRR
1	30	2	2	2	200	1.7637	1.12
2	30	2	2	2	350	2.2222	1.35
3	30	2	2	2	500	2.1982	1.76
4	30	5	4	4	200	1.7566	1.16
5	30	5	4	4	350	2.0207	1.43
6	30	5	4	4	500	2.2066	1.55
7	30	8	6	6	200	2.5473	0.899
8	30	8	6	6	350	2.3488	1.93
9	30	8	6	6	500	1.9946	2.67
10	45	2	4	6	200	1.6245	1.45
11	45	2	4	6	350	1.391	1.78
12	45	2	4	6	500	1.7243	2.47
13	45	5	6	2	200	2.1767	1.49
14	45	5	6	2	350	1.7777	2.18
15	45	5	6	2	500	1.8418	2.31
16	45	8	2	4	200	1.8238	1.59
17	45	8	2	4	350	2.0857	2.11
18	45	8	2	4	500	1.8598	2.64

19	60	2	6	4	200	1.6395	1.72
20	60	2	6	4	350	1.6402	1.92
21	60	2	6	4	500	1.6651	1.68
22	60	5	2	6	200	1.4959	1.33
23	60	5	2	6	350	1.9078	1.93
24	60	5	2	6	500	1.8914	2.87
25	60	8	4	2	200	2.0836	1.38
26	60	8	4	2	350	2.0134	2.18
27	60	8	4	2	500	2.044	3

3. RESULTS AND DISCUSSIONS

The effect of machining parameters, i.e., rotational speed, spark gap and pulse off time on material removal rate and surface roughness will be discussed in this section. This section is based on the observations analysed from the set of experiments.

3.1 Analysis of machining parameters on Material Removal Rate

Material Removal Rate (MRR) is one of the most significant output parameters to be analysed during the Wire Electrical Discharge Turning (WEDT) process. MRR is theoretically calculated using the formula-

MRR = π (R2 – r2) vf, where,

vf = l/t

l – Machining length
R – Radius before machining

3.1.1. Influence of Spark gap voltage

Spark gap is the factor that influences the gap resistance. It is that with the decrease in the spark gap from 60 to 30V, the MRR is also found to increase. This is due to the increase in gap resistance. At lower spark gap, gap resistance is less and breakdown occurs at a faster rate, and hence the number of discharges per unit time is increased. When the number of discharge increase, the gap contamination will be more and the chances of forming arcs and arc regions increase.

t – Machining time
r – Radius after machining

3.1.2 Influence of pulse on-time

Pulse on time varied from 5to 8μs, the MRR is found to increased. This can be attributed to the fact that number of discharge is increased causes high discharge energy which removes the material faster.

3.1.3 Influence of pulse off-time

Increasing the pulse off time factor from 2 to 6, the MRR also keep on increased. It is thus seen that with the increase in pulse off time, the MRR is increased. This can be attributed to the reduction in the total number of discharges per unit time since MRR is proportional to the number of discharges and also depends on the type of discharge.

3.1.4. Influence of wire speed

Increasing the wire feed factor from 2 to 4, the MRR is found to increase from 1.687 to 1.997 (Table 3). This is due to high intensity of spark created between brass wire and work- piece.

3.1.5. Influence of Rotational Speed

Rotational Speed has significant influence on the number of arc regions. It is observed that as the rotational speed is varied from 200 to 500 rpm, the MRR is found to increase.

3.2. Analysis of machining parameters on surface finish

The effect of various machining parameters such as Pulse-off time, Spark gap and rotational speed on surface roughness are analysed in this section. The surface roughness is measured using Ra value which is represented in Table 2. These are obtained by varying the input machining parameters. The surface roughness is measured with the help of a Mahr roughness tester. Roughness is measured at 3 locations along the circumference of the WEDT. Surface finish in EDM or WEDM depends on discharge energy.

3.2.1. Influence of Spark gap voltage

With increase in spark gap voltage, from 30 to 45 V, the Ra value is found to decrease from 2.118 to 1.812 µm (as shown in Table 4). This is due to the reduction in the number of discharges and the number of arc regions with increase in spark gap. The width of arc region is less at higher spark gap compared to that of the lower one due to this Rz value reduced.

3.2.2. Influence of pulse on time

With the increase in pulse on-time from 2 to 5 um, the Ra value is found to increase from 1.763 to 1.897. Longer spark creates non-uniform crater on the surface causing unevenness on the whole circumferential length of the work piece.

3.2.3. Influence of pulse off time

With increase in pulse off time from 4 to 7 Ra value is reduced from 2.32 to 2.05 µm (as shown in Table 4). The increase in pulse-off time causes a reduction in number of discharges per unit time. This is due to reduction in energy per unit time which is due to reduction in number of discharges per unit time. It is inferred that increase in pulse off time value results in decrease in Ra value.

3.2.4. Influence of wire feed factor

With the increase in wire feed factor from 2 to 6, the Ra value is found to decrease from 2.013 to 1.811. This is due to uniform intensity of spark generated to the whole circumferential length of work piece.

3.2.5. Influence of spindle speed

With the increase in spindle speed from 200 to 500 rpm, the Ra value increases. This can be attributed to the fact that at higher rotation speeds, the chance of irregularly cut profiles increases.

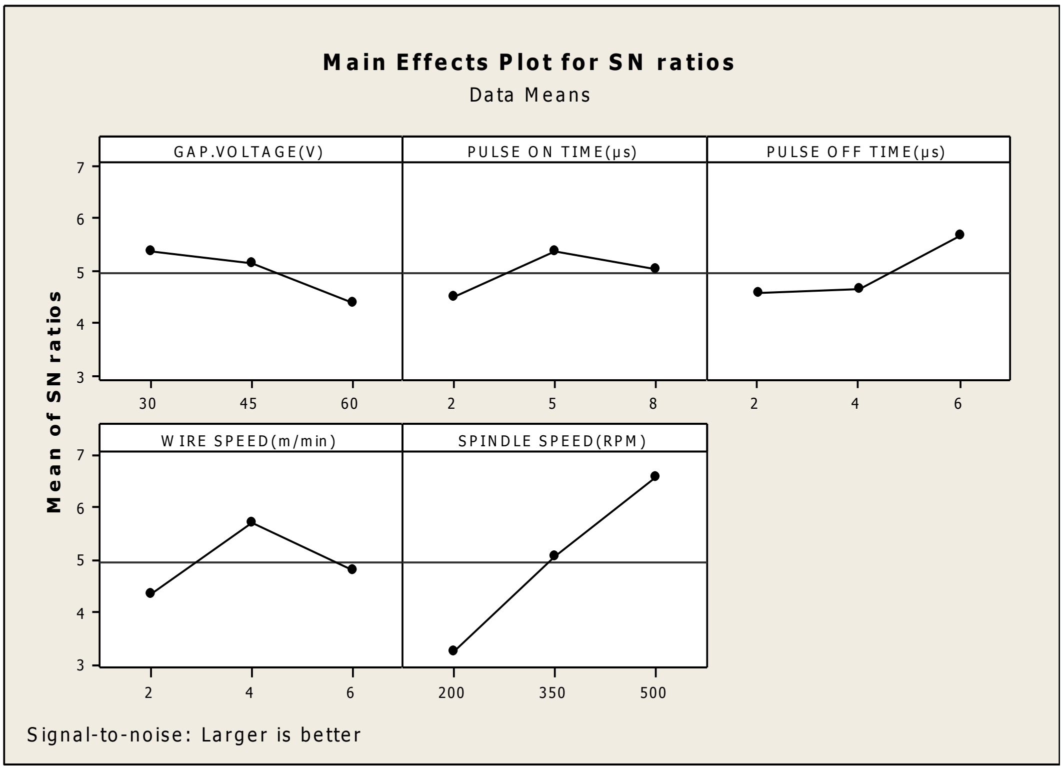

Fig.3 Variation of MRR

Table 3 Response table for means

Levels	Gap Voltage(V)	Pulse on Time(μs)	Pulse off Time(μs)	Wire Speed(m/min)	Rotational Speed(RPM)
1	1.956	1.701	1.762	1.687	1.476
2	1.862	1.908	1.748	1.997	1.832
3	1.679	1.888	1.987	1.813	2.189
Delta	0.278	0.208	0.239	0.310	0.712
Rank	3	5	4	2	1

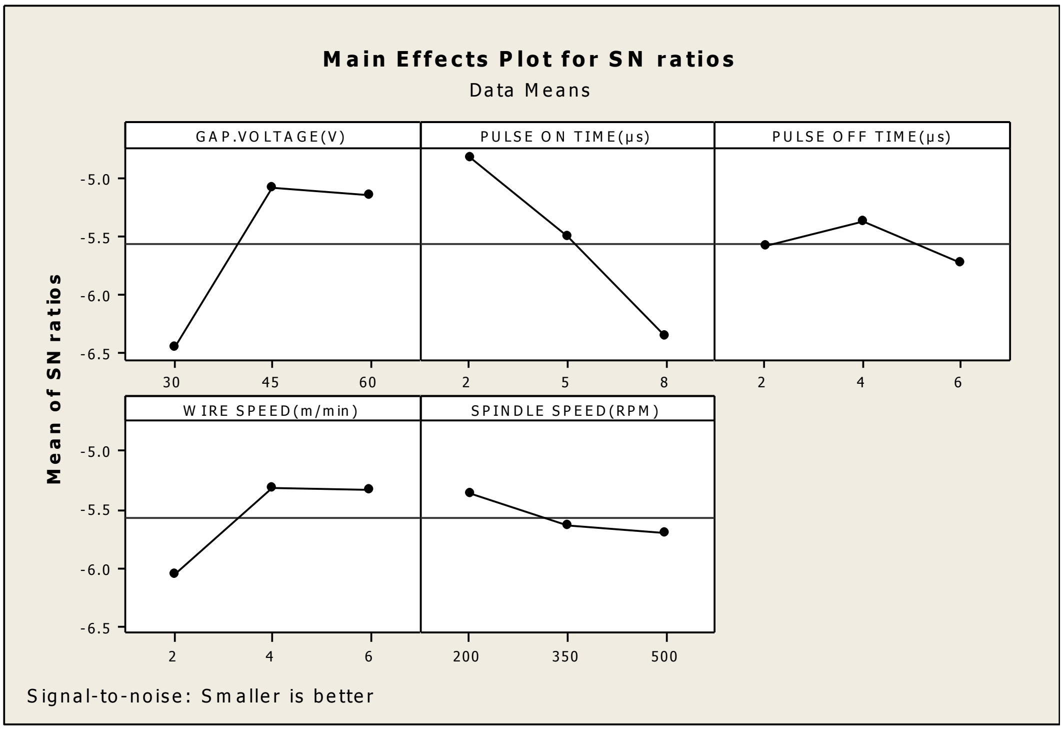

Fig. 4 Variation of R_a

Table 4 Response table for means

Levels	Gap Voltage (V)	Pulse on Time (μs)	Pulse off Time (μs)	Wire Speed (m/min)	Rotational Speed (RPM)
1	2.118	1.763	1.917	2.013	1.879
2	1.812	1.897	1.874	1.855	1.934
3	1.820	2.089	1.959	1.881	1.936
Delta	0.306	0.326	0.085	0.158	0.057
Rank	2	1	4	3	5

The following surface profiles were obtained from the experiment:

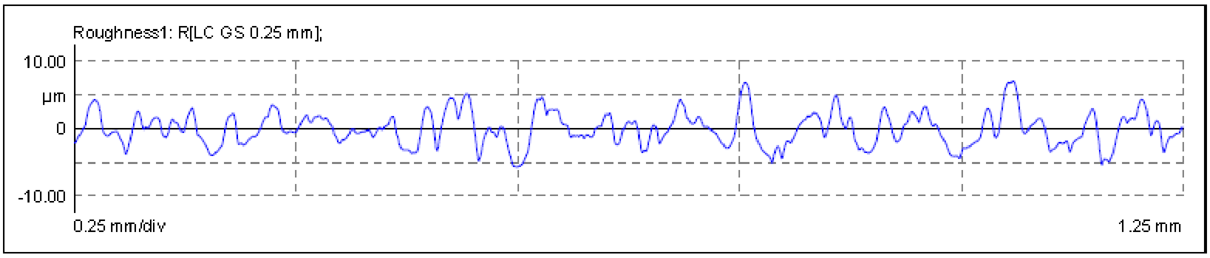

Fig. 5 Surface profile for first trial

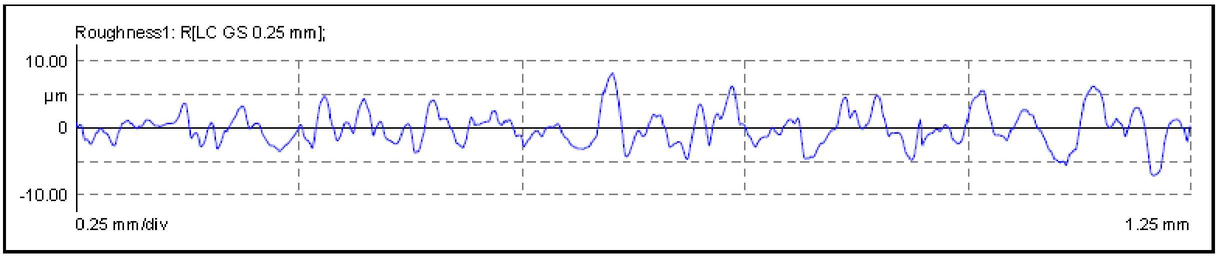

Fig. 6 Surface profile for second trial

5. CONCLUSION

In this research, various analyses were performed to present the effects of machining parameters like pulse-off time, pulse-on time, wire feed rotational speed and spark gap on the material removal rate and surface roughness. For the WEDT process a setup was developed to perform experimentation.

The effects of the machining parameters are studied using the Taguchi method. Taguchi method determines the factors which have significant impact on material removal rate, surface roughness. The optimal setting is found by means of Signal to Noise ratio analysis. The larger is better approach is applied for MRR while smaller is better approach is used for the surface roughness. The parameters are optimized for getting a larger MRR and smaller surface roughness value (Ra).

The following major conclusions are drawn from the experimentation:

MRR is most significantly influenced by rotational speed (as shown in table 3) with maximum value of MRR as 2.189 mm3/min at 500 rpm. At spark gap of 30 V, maximum MRR value is obtained as 1.956 mm^3/min. Pulse on time is found to be least significant with highest MRR of 1.908 mm3/min observed at 5 µs.

Surface roughness is most significantly influenced by pulse on time (as shown in table 4) with maximum value of Ra as 2.089 µm at pulse on time of 5 µs. For pulse off time of 6 µs, maximum value of Ra is obtained as 1.959 µm. Rotational speed is found to be least significant with highest Ra of 1.936 µm at 500 rpm.

REFERENCE

[1] T. Masuzawa and H.K. Tonshoff, Three-dimensional micromachining by machine tools, *CIRP Ann.*, 46, 1997, 621–628.

[2] K.P. Rajurkar, and Z.Y. Yu, Z.Y, 3D micro-EDM using CAD/CAM. *CIRP Ann.,* 49, 2000, 127–130.

[3] T. Masuzawa, K. Okajima, T. Taguchi, and M. Fujino, EDM-lathe for micro-machining. *CIRP Ann.,* 51, 2000, 355–358.

[4] A. Mohammadi, A. Fadaie Tehrani, E. Emanian, D. Karimi and H. Jafarpisheh, A new approach in turning by wire electrical discharge machining to evaluate the effects of machining parameters on MRR, *Proceedings of the Tehran International Congress on Manufacturing Engineering*, Tehran, Iran, December 12–15, 2005.

[5] V. Janardhan and G.L. Samuel, Pulse train data analysis to investigate the effect of machining parameters on the performance of wire electro discharge turning (WEDT) process, *International Journal of Machine Tools and Manufacture*, 50, 2010, 775-788.

[6] D. Scott, S. Boyina and K.P. Rajurkar, Analysis and optimization of parameter combination in wire electrical discharge machining. *Int. J. Prod. Res.,* 29, 1991, 2189–2207.

[7] K.P. Rajurkar and W.M. Wang, Thermal modeling and on-line monitoring of wire EDM. J. Mater. *Process. Technol.*, 38, 1993, 417–430.

[8] Y.S. Liao, J.T. Huang and H.C. Su, A study on the machining parameters optimization of wire electrical discharge machining. *J. Mater. Process., Technol.*, 71, 1997, 487–493.

[9] J.T. Huang and Y.S. Liao, Optimization of machining parameters of wire EDM based on grey relational and statistical analyses. *Int. J. Prod. Res.*, 41, 2003, 1707–1720.

[10] P.M. George, B.K. Raghunath, L.M. Manocha and A.M. Warrier, EDM machining of carbon-carbon composite-a Taguchi approach. *J. Mater. Process. Technol.*, 145, 2004, 66–71.