Effect of machining parameters in wire-electrical discharge turning process: A review

Gajanan M Naik[1*], S. Narendranath[2]
[1, 2] *Dept of Mechanical Engineering, NIT, Karnataka, Surathkal, Mangalore, India.*
**E-mail id: gajamnaik@gmail.com*

***Abstract*— The Wire Electrical Discharge Turning (WEDT) supports to generate cylindrical part, which is hard and difficult to machine materials under conventional machining operation. WEDT process is a one of the prominent machining process to develop a turned object for specific industrial applications. This literature review, reviews the effect of machining parameters, such as power, time-off, voltage, servo, wire speed, wire tension, and work piece rotational speed factors on the MRR, Surface integrity, Roundness and published microstructures of carbide, brass parts and high tensile steel are investigated by using Scanning Electron Microscope (SEM) to observe crater, heat affected zone, recast layer and bubble formation on the turned surface. It is essential to optimize the process parameters and to increase machinability, productivity.**

***Keywords*— WEDT or Cylindrical Wire Electrical Discharge Turning; Material Removal Rate; Surface roughness, roundness, Microstructures.**

I. INTRODUCTION

Electric discharge machining (EDM) is a Thermo electric non-traditional machining process it erodes the material from the work piece by melting or vaporizing. It is an advanced machining process primarily used for hard metals which are difficult to machine by using conventional machining and it is best suitable for making intricate shapes and cavities, the contours which would be difficult to machine with conventional or traditional techniques, however only electrically conducting materials can be machined by this process [1, 16]. The EDM process classified in to three types those are Die sinker EDM, Wire EDM and powder mixed EDM. The wire electrical discharge machining (WEDM) is a type of EDM which is popularly used in metal cutting industry, it is also known as wire-cut EDM here the erosion from the material takes place by electric spark [5], a thin metal wire, usually zinc coated brass or copper or tungsten of diameter 0.05-0.3mm, nominal diameter of 0.25mm [17], this small diameter wire can achieve the very small corner radii, when it is fed through the work piece submerged in a tank of insulated dielectric fluid, typically de-ionized water[1]. The EDM and WEDM process has a major application in the field of automotive, aerospace, moulds, tool and die making industries, also be found in the medical, optical, dental, jewellery industries, micro gas turbine blades, electronic components, production and in R & D laboratories. Another popular application for EDM and WEDM is the machining of extrusion dies [3, 4, 15]. The wire cut EDM is restricted to machine sheet cutting, but now it is established for machining of cylindrical job, this is done by adding a rotary axis to a conventional five axis wire EDM machine; this is known as wire electric discharge turning (WEDT) or cylindrical wire electric discharge turning (CWEDT) . Illustrated in Fig 1[1, 17].

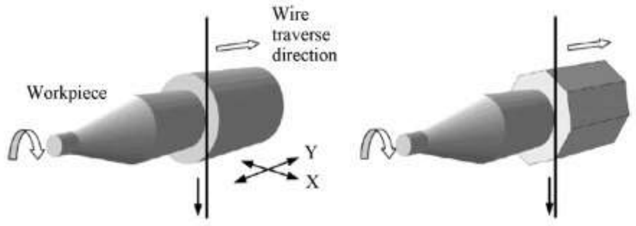

Fig 1:Turning with Wire-EDM [1]

In this paper, literature review of cylindrical wire Electric Discharge turning process discussed and made to understand the material removal rate, surface finish and roundness, SEM micrographs to investigate the CWEDT surface, under different machining parameters.

II. WIRE-ELECTRICAL DISCHARGE TURNING PROCESS

The cylindrical wire-electric discharge turning process is illustrated in Fig.2. A rotary axis is added to a conventional five axis wire-Electric Discharge Machine, in order to generate a cylindrical object. In wire electric discharge turning process, the work-piece is rotating which is driven by a spindle and it is submerged in a tank of de-ionized water. Two jets of high-pressure water are used to flush the work-piece to improve the material removal rate and to maintain a uniform thermal environment motor is placed on the top of the spindle assembly; a timing belt is used to transmit the rotational motion to spindle. While machining, the work material starts to rotate with the help of spindle and motor, at the same time wire is moving towards the work to be machined, an interelectrode gap is maintained between tool and the work-piece. Depending upon the applied potential difference and the gap between tool and the work-piece an electric field were established, however the material removal takes place by means of electric spark, and it generates cylindrical shape. An example of the diesel fuel system injector plunger machined using the cylindrical wire-EDT, has been shown in Fig.3 [10].

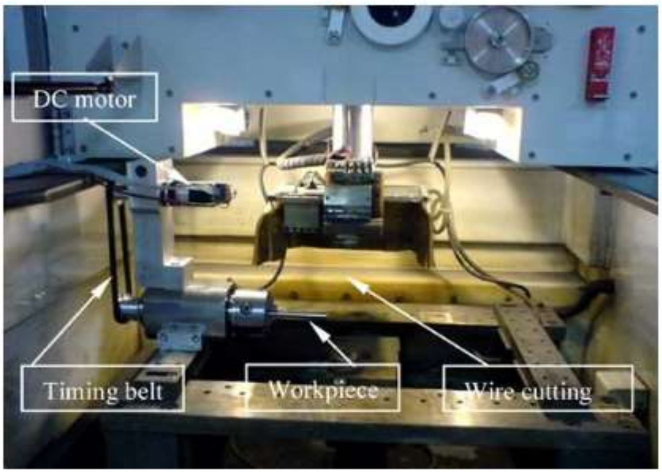

Fig 2: Experimental Setup of the five-axis Cylindrical Wire Electrical Discharge Turning (CWEDT) machine [8]

Fig 3: A cylindrical wire EDM part with the same shape as the diesel engine injector plunger [10]

III.LITERATURE REVIEW

A. MATERIAL REMOVAL RATE.

Machining is a process designed to change the shape, size, and surface of a material through removal of materials that can be achieved by straining the material to fracture or by thermal melting and evaporation. The material removal rate it is a volume of material removed per unit time (mm^3/min), this plays an important role to increase the productivity of manufacturing industry, and MRR also defines the performance of machine [3]. The material removal rate of WEDT can be calculated by using equation (1) below given. [1,13].

$$MRR=\pi(R^2-r^2)v_f \quad (1)$$

$$V_f = l/t \quad (2)$$

Where R original radius of the work-piece in mm,

r final radius of the work piece after machining in mm,

V_f machining cutting speed or feed rate in mm/min,

l machining length in mm,

t is the machining time in min.

Mohammad Jafar Haddad, Alireza Fadaei Tehran [1, 20] reported the material removal rate of CWEDT for AISI D3 (DIN X210Cr12) [14] tool steel, based on statistical analysis by using design of experiment (DOE) method. The input factors of power, voltage, pulse off time and spindle rotational speed have most significant effect on MRR. Increase in power and voltage cause MRR to increase significantly, but the pulse off time and spindle rotational speed shows inverse effect on MRR. Illustrated in Fig 4.

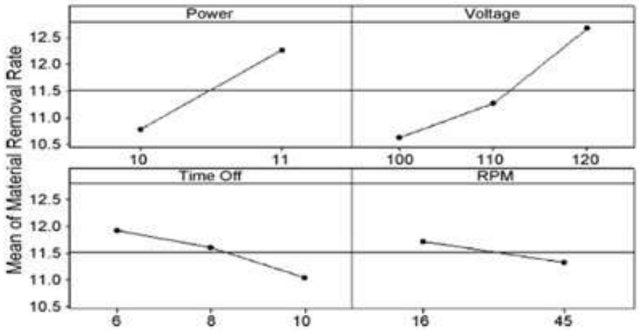

Fig 4: Effects of Machining Parameters on MRR [1]

Aminollah Mohammadi et al. [8] investigated the material removal rate (MRR) by Taguchi standard orthogonal array for the design of experiments and Analysis of variance (ANOVA) accomplish on experimental result under different machining parameters like servo voltage, power, wire speed, rotational speed, voltage, wire tension and time off. From the experimental data author observed that the power and voltage have a significant effect on material removal rate, here the power and voltage are directly proportion to the MRR and other factors shows the inverse effect on MRR. P. Matoorian et al. [7] studied the Taguchi robust design method to investigate the effect of machining parameters on cylindrical wire electrical discharge turning operation. The factors of voltage, intensity, spindle speed shows the major influence on MRR, by increasing above parameters the MRR increases, the servo, pulse on and off time shows reverse effect on MRR. Jun Qu et al. [10] have examined by adding spindle to the two-axis conventional wire electric discharge machine in order to get a cylindrical turned job, this investigation was conducted to know the variations of material removal rate on carbide and brass materials based on process parameters. According to the experimental results the brass material shows higher MRR compare to carbide this is because of the high thermal conductivity and low melting temperature of brass, it is also observed that the effect of rational speed and wire feed rate on MRR. D. Balamurali et al. [13] reported the effect of machining parameters on MRR in cylindrical wire electric discharge machining process. The experiment was done with stainless steel of grade (316) material, because of its growing application in manufacturing industry. The machining parameters of rotational speed, pulse off time, pulse-on time, wire feed and spark gap were analyzed using design of experiments based on Taguchi method. From experiments it is found that the MRR increases, when the voltage and rotational speed of the spindle is high and it is also concluded that the signal to noise ratio is should be more for optimal better approach of MRR. M. Parthiban, C et al. [15] analysed the wire electric discharge machining to introduce wire electric discharge turning and wire electric discharge grinding process.

In the assembly setup the author observed that the spindle error due to bearing failure and assembly error due to EN24 spindle material; this is minimized by replacing spindle material from EN24 to EN8 and ball bearing to angular contact bearings, after resolving spindle error problem, the tungsten rod was machined to investigate. S. Aravind Krishnan & G. L. Samuel [19] worked on WEDT process using an artificial neural network (ANN) with feed-forward back-propagation algorithm, adaptive neuro-fuzzy inference system. The experiments were investigated based on Taguchi design of orthogonal array L27 is used to train the neural network and to test its performance. The output parameter was optimized by a multi-objective optimization method; it is based on non-dominated sorting genetic algorithm-II. From the data it is found that the material removal rate, MRR is high when the pulse off time and spark gap is moderate, servo feed is high and at low rational speed. V. Janardhan, G.L. Samuel [21] have investigated the effect of machining parameters on MRR; this is done by developing data acquisition system. The author did conduct experiment on both wire electric discharge machine (WEDM) and wire electric discharge turning (WEDT) in order to study the material removal rate, this is done by considering five process parameter in three levels, from the data it is observed that at lower pulse off time, spark gap, servo feed, flushing pressure and rotational speed the MRR obtained is high in both WEDM and WEDT, and it also showed that the MRR is less in WEDT compare to WEDM, the material used in machining is Brass.

B. Surface integrity and Roundness.

Aminollah Mohammadi et al [9] examined the surface integrity and roundness of workpiece created by the cylindrical wire electric discharge turning process. The experiments were conducted to investigate the surface finish and roundness generated under different machining parameters of power, time off, voltage, servo, wire tension, wire speed and rotational speed. According to the data obtained from the investigation the input power increases the surface roughness increases, also it shows higher material removal rate, the other factors shows moderate surface roughness on material, in order to achieve good surface finish the process should maintain the lower power input. The roundness variation on material with respect to the machining parameters are also observed from experiments, therefore by increasing the servo voltage the roundness can be minimized, other than servo voltage the rest of the machining parameter shows insignificant effect of roundness. Jun Qu et al. [6] have studied on brass and carbide materials to examine the surface finish and roundness under different machining parameters. In experiment I they have considered two process parameters there are wire feed and rotational speed,the surface finish was calculated using a Taylor Hobson Talysurf stylus profiler, here it is observed that at lower wire feed rate the surface roughness is lower and at higher spindle speed the surface roughness is higher visa versa, The roundness of the machined parts was calculated by using the Mahr Formtester MMQ40 form measurement machine, from this study it is came to know that the better roundness is accomplished at lower wire feed rate. In experiment II the wire feed and pulse on time are considered as a major machining input parameters, here the author observed that the better surface finish and roundness can be achieved by maintaining lower feed rate and small pulse on time, because at lower pulse on time the spark generated is small so that the crater formation also small that leads to better surface finish. D. Balamurali, et al. [13] conducted experimets on WEDT by considering gap voltage, pulse on time, pulse off time, wire speed and rotation speed in three level as a input parameter and it is analyzed by using design of experiment method (DOE). According to them when the spark gap voltage, pulse off time and wire feed increases, the surface roughness decreases, on the other hand the pulse on time and rotational speed shows direct effect on surface roughness, that means when pulse on time and rotational speed increases the surface roughness also increases. This investigation was done on stainless steel of grade (316).S. Aravind Krishnan & G. L. Samuel [19] experiments was carried out on WEDT process in order to examine the surface roughness under three levels, varied input parameters are pulse off time, spark gap, servo feed and rational speed, the material used in this investigation was AISI D3 tool steel. The data of orthogonal array L27 shows low surface roughness of high pulse off time and rotational speed, at moderate spark gap and low servo feed. The surface roughness of the turned material is measured on MAHR Perthometer using MarSurf XR 20 software, with a cut-off length of 0.25 mm. V. Janardhan, G.L. Samuel [21] presented on brass material here The pulse off time, spark gap, servo feed, flushing pressure and rotational speed were considered in three level, as a input parameters, according to the experimental result the author stated that by increasing the pulse off time, spark gap, surface roughness reduces, the flushing pressure and rotational speed does not show the significant effect on surface roughness, here by increasing the above two parameter slight decrease in surface roughness can observed and the servo feed shows the direct influence on surface roughness. The roundness is calculated with the Mahr roundness tester on three different location of the component and its average is listed out, from the result it shows that the roundness decreases by increasing the pulse off time, spark gap, flushing pressure, rotational speed, and the roundness increases by increasing servo feed, so it is conclude that the surface roughness and roundness reduced by reducing the arc regions per unit time.

C. Surface Micrographs.

Jun Qu, et al [6, 20] have investigated on turned Brass and carbide material by using Scanning Electron Microscope, based on the observation held in the experiments, crater, recast layer, bubble, and heat effected zone are located on the surface of two different material. Illustrated in the Fig 5,6. The crater size is observed on carbide and brass machined under same pulse on-time, here it is found that at lower pulse on time the crater size get reduced and it also observed that the crater size is slightly larger on brass surface compared to the carbide surface this is because of the influence of pulse on-time and thermal conductivity of the material. The recast layer is the re-solidified layer on the material after machining due to electric spark, at shorter pulse on-time the thinner recast layer and lower depth of heat effected zone are observed, also the bubbles have observed in the recast layer, this is because of the presence of thermal stresses and tension cracking.

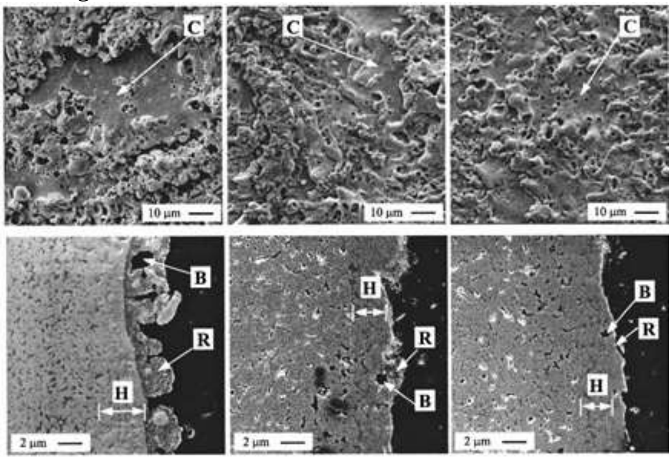

Fig 5: SEM micrographs of surfaces and cross-sections of carbide parts [6]

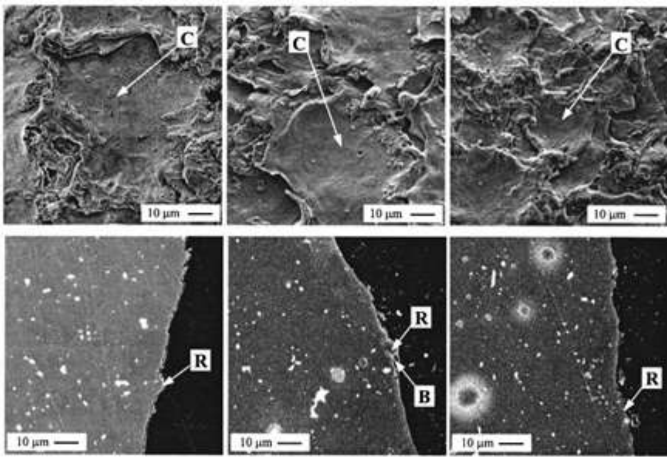

Fig 6: SEM micrographs of surfaces and cross-sections of brass samples [6]

C: Crater, R: Recast layer, H: Heat Effected Zone, B: Bubbles

Abimannan Giridharan & G. L. Samuel [18]: This research paper investigates the formation of crater during wire electrical discharge turning process, this analysis is done on high tensile steel [AISI4340] material, anode erosion method and finite element methods is used to predict the crater diameter. The machined job is inspected through SEM, from the observation it is found that the crater diameter formed on machined part is increased with increase in the discharge energy. Shown in SEM micrograph [18] at different servo feed and size of the crater (C) is measured using 3D topography.

IV. Summary

The study of various machining parameters of wire-ED Turning shows that the MRR increased by increasing the power and voltage, the power has a significant effect on surface roughness and the effect of power, wire speed, servo on roundness had observed in the literature. Table.1 shows the summary of effects of machining parameters on MRR, surface roughness and roundness.

Table 1: Effect of machining parameters on process outputs in WEDT

Input parameter \ Output parameter		MRR (mm^3/min)	Surface Roughness (μm)	Roundness (μm)
Power(Watt)	Increases	↑	↑	↓ to small extent ,then ↑
Voltage(Volt)	Increases	↑	↑	↑
Servo(Volt)	Increases	↓	doesn't affect	↓
Wire Speed(mm/min)	Increases	↑	↓ to small extent ,then ↑	↑
Wire Tension(grm)	Increases	↓	↑ to small extent ,then almost constant	↓ to small extent ,then ↑
Rotational Speed (rpm)	Increases	↓	↓ to small extent ,then ↑	↓ to small extent ,then ↑
Time off (μs)	Increases	↓	↑	↓ to small extent ,then ↑

V. Conclusion

Higher accuracy of MRR through references has been demonstrated successfully in this literature review work. A selection of various machining parameters i.e. power, time-off, voltage, servo, wire tension, wire speed and rotational speed, the effects on MRR, Surface roughness and roundness concluded below.

1. Material removal rate is significantly influenced by power and voltage with maximum value of MRR, and by increasing servo voltage the MRR decreases, wire speed, rotational speed, wire tension, pulse off time have moderate effect on MRR.
2. The effects of power, time-off, voltage, servo, wire tension, wire speed, and rotational speed on surface roughness and roundness are reviewed from the literature, according to the experimental results, only power has a significant effect on the surface roughness and none of the factors have a significant effect on surface roughness. The effects of wire speed, power, and servo on roundness are more significant than time-off, voltage, wire tension, and rotational speed.
3. The Carbide and brass parts are machined by using cylindrical electric discharge turning machine, surface craters, recast layers, and heat-affected zones are observed, and their sizes are estimated using the Scanning Electron Microscope (SEM), also observed that the crater diameter increases with increases in discharge energy on high tensile steel, the discharge energy decreased by increasing servo and spindle

speed, so that the crater formed on machined part can minimized.

VI. FUTURE WORK

The wire-electric discharge turning operation can be carried out by using different wire materials like zinc coated brass or diffused brass or copper or tungsten wire to optimize the machining parameters. Also the experiment can be conduct on different materials like steels, aluminum, brass, titanium, shape memory alloys, super alloys Inconel718, Inconel 600 etc.

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