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Abstract- The present research work is intended to optimize the machining parameters for achieving high dimensional accuracy in wire electric discharge machining (WEDM). Experiments were designed and carried out to evaluate the best parametric setting which gives parameters like power, spark gap and corner radius using Inconel X-750 as workpiece material. These parameters are determined for a wide range of job thickness and mathematical correlations were developed for the parameters such as power and spark gap. Analysis of variance (ANOVA) is also performed to study the fitness. This procedure eliminates the need for repeated experiments which saves time and material unlike conventional machining process. The primary objective of the study is to find out the important and combination of one or more factors that influence the machining process in order to achieve the best power setting in turn machining current. Also, Machinability index of various materials which can be machined by WEDM is evaluated by referring to the present research work and literature review. The index may be useful to the fraternities like industry and academia in determining the best cutting parameters that are to be set on the machine. The best parameters evaluated out of this study, will be useful while setting up the machine which avoids trial and error method and also aids in process planning.

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I. Introduction

Worldwide industry acceptance has brought revolutionary changes in bringing the Wire electrical discharge machines (WEDM) into the shop floors which is an unconventional production process thus manufacturing the components with a complex geometry.

The material is removed from a workpiece by creating a series of rapidly recurring electric current discharge (thousands of sparks) between the cutting tool and workpiece, immersed in a non-conductive fluid called dielectric.

The wire used for machining is also called as a tool/electrode and is made of copper, brass, tungsten or brass coated of diameter varying from 0.03 to 0.30mm.

A constantly moving wire fed from a spool is subjected to a high tension with the help of an advanced tension servo control mechanism shall results in producing precision components of extremely complex shape and desired profile.

The WEDM can be deployed to machine the materials that are hard to machine such as high strength and temperature resistive materials (HSTR). Also, the components manufactured out of Wire EDM would be free from the geometrical changes as there won't be any mechanical stresses developed during the machining. The dimensional accuracy can be achieved even in the case of machining the heat treated materials regardless of the hardness. Hard or difficult to machine materials are also can be machined using the WEDM.

The mechanical stresses that are developed during the machining process would be eliminated as there would not be any direct contact between workpiece and the tool. It may be observed that the material is eroded ahead of the wire travel.

The first commercially NC machine was built and introduced to the manufacturing industry in the late 1960s. The WEDM process was developed as a result of quest of a technique to replace the machined EDM electrode. D.H. Dulebohn has automated the WEDM process and controlled the shape of the machined components with the help of optical-line follower technique in 1974. The process has become very popular by the year 1975 and by then the industry has good understanding and knowledge about various capabilities of WEDM. Later, it was observed that there was rapid growth in deploying the WEDM machines in the manufacturing segment.

The first CNC EDM was fabricated in late 1970s which has brought a major evaluation of the machining processes.

As a result, the wide range of capabilities of the WEDM process were significantly implemented for any

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through hole machining owing to the wire, which has to pass through the component to be machined. The WEDM applications includes Prototype production, die making, closed loop manufacturing, metal disintegration machining, Extrusion Dies, Fixtures and Gauges, Form tools and inserts, Bio-Medical applications, Aerospace, defense and electronic parts. Limited varieties of composites and ceramics also can be machined using WEDM. Fig.1. shows the schematic view of the process.

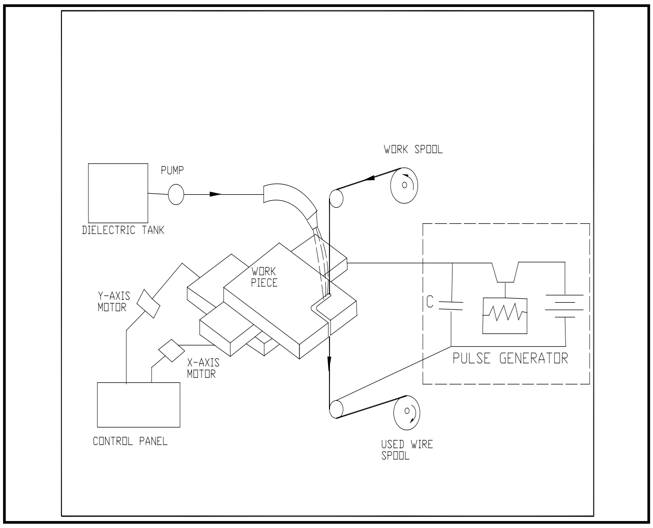

Figure1 : Wire electrical discharge machining Process

WEDM removes material with the help of a storage capacitor by releasing a series of discrete electrical discharges (transient sparks over a shorter duration). The erosion takes place when the capacitor starts discharging an electrical current through an accurately positioned and constantly moving wire (tool/electrode) and the workpiece (anode). A narrow gap is maintained between the tool and cathode through an insulated medium (dielectric fluid). A microprocessor embedded with the WEDM machine maintains a constant narrow gap varying from 25 to 50 microns between the electrode and workpiece.

When the wire approaches close to the workpiece, the controlled electrical discharges creates a concentrated spark that helps melting down the required portion of material into vaporized tiny particles during the erosion process.

The workpiece is totally submerged in dielectric fluid which would help in maintaining constant temperature and also flushes away the debris after erosion. Flushing mechanism plays a vital role when there is a change in thickness of the workpiece.

The flushing mechanism even aids in cooling down the workpiece after erosion and surrounding environment handling huge temperature range of 10000°C. The volume of the material removed per spark may be 10-6 mm3 approximately.

WEDM does not require customized form or a shaped electrode as there is only a wire used as a tool which saves investment of resources like cost, time and money. Unlike traditional machining, the WEDM process eliminates use of different electrodes for rough and finish operations. Sometimes, the finish operation may demand multiple passes along the profile/shape to be created.

WEDM can achieve exceptionally high dimensional accuracy as it uses a thin and continuous wire feeding through the workpiece and enables the production of parts particularly a complex shape.

Surface finish quality depends on the amount of electrical discharge energy and also relates to the intensity and duration of the spark plasma. Decrease in both pulse duration and discharge current may influence Surface finish, cutting speed and MRR.

Machining Parameters influencing the WEDM process Discharge Current, Gap Voltage, Pulse parameters like pulse frequency and duration, Conductivity, flow rate and flushing pressure of dielectric fluid, dielectric flushing pressure, wire size, material, speed and tension, thickness, melting point, material of workpiece etc.,

a) Experimental Set-Up

The experimental studies were performed on a Wire EDM machine of make ULTRACUT 334.

A brass wire of 250 microns diameter is used as a tool-electrode with a wire tension of 70N at a velocity of 3.4 m/min. Inconel X-750 is used as a workpiece material for conducting the experimentation. As per DIN 160 standards, the preferred mechanical strength of the brass alloy wire opted for the experimentation is of 900 N/mm2 with a composition of CuZn36.

Deionized water with a dielectric conductivity of a value of 38 mhos is used as a Dielectric medium for the present study. A range of 30 to 90 Volts has been set as a gap voltage. The optimum values were obtained at 80 Volts.

Experimental investigation was done to find out the influence of the current with respect to the parameters like varying workpiece thickness, spark gap and the geometry. Workpiece thickness of Inconel X-750 material used was varying from 5 to 80mm material.

As shown in Fig.2, an "L" shaped cut was performed to measure the corner radius with respect to the current value and also another slot of 30mm length has been cut to measure the slot width. Series of experiments were carried out varying the workpiece thickness starting from 5 to 80 mm with an increment of 2.5mm or 5mm as convenient. A total of 20 experiments were conducted in the present research work.

Necessary care was taken to achieve high cutting speed with respect to varying current with a least wire breakage.

Figure 2 : Shape of the slots machined

The instrument, Nikon OPTOMECH-Rapid-optical microscope with a 100X magnification is used for measuring the workpiece after cutting. Necessary parameters related to corner geometry were recorded and tabulated for quick reference.

The spark gap can be derived using the equation W = d + 2 * Sg Where W= Slot width, d = Wire diameter and Sg = Spark gap

The variation of power, spark gap and corner radius with respect to change in thickness of workpiece is discussed in this article to derive the best fit curve. Origin 8.0 software tool is being used for the study. The mathematical equations are derived and statistical analysis ANOVA is also performed to calculate the co-efficient of variance, R2 and standard deviation in order to determine the fitness of the curve.

b) Results and Discussions

Fig.3. describes the effect of variation in thickness with respect to the power. The increase in workpiece thickness causes variation in power. It is also observed that the increase in workpiece thickness causes increase in machining current for a specific set of machining conditions.

This phenomenon reveals that the high amount of energy required to machine higher workpiece thickness, the machining can be performed only when the current is increased which involves high amount of power. However, the rate of power change is found decreasing with increasing thickness. This may be due to the limitation of current carrying capacity of the wire electrode.

The plot is useful to determine suitable values like the minimum power required for machining the INCONEL X- 750 workpiece at given thickness with in working range of the select machine.

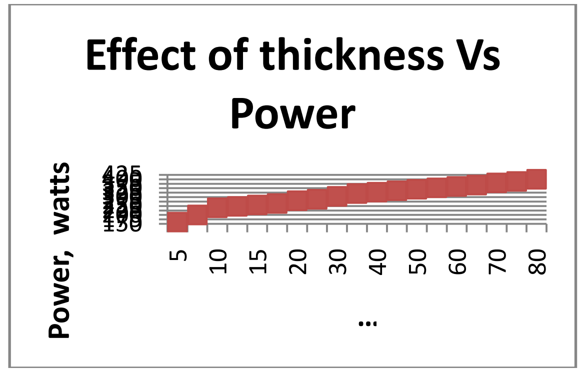

Figure 3 : Effect of Thickness on Power

The power required in turn the machining current can be selected from the plot for a given thickness of the job.

By regression and correlation of the available data, the mathematical expression for the best fit curve is derived as given below.

Power (P) = 400.16 - [80 x 5107.31 / (1 + exponential of {(T+223.8) / 26.3 })] Eqn. (1)

Fig.4 depicts the trend of variation in spark gap with the increase in workpiece thickness. The plot shows that the spark gap increases with increment in workpiece thickness. The increase in gap may be due to the spark jumping longer because of high energy generated at high current values, is required to machine the job of higher thickness, though the rate of change is proportionate with respect to the job thickness. The best fit curve is plotted and is carried out the statistical analysis (ANOVA).

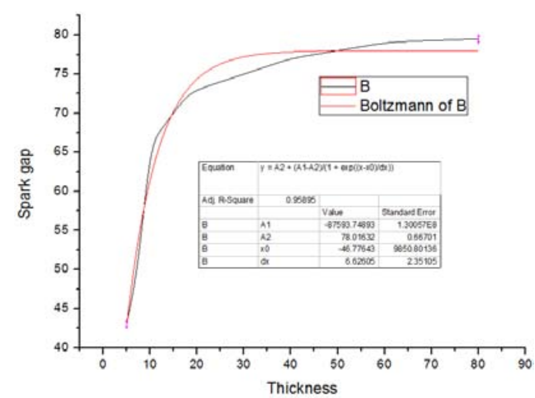

Figure 4 : Effect of Thickness Vs Spark gap

The mathematical relation can be expressed as

Spark gap (Sg) = 78.016 - [87671.75 / { 1 + exponential of { (T+46.77) / 6.63} }] Eqn. (2)

Where Sg in micrometers.

The outcome of statistical analysis gives the value of R-Squared and standard deviation as 0.9657 and 0.2557 respectively. This is useful in finding the spark gap i.e., the cutting width to compute the MRR and determine the wire offset used while generating a CNC part program and hence high accuracy can be achieved.

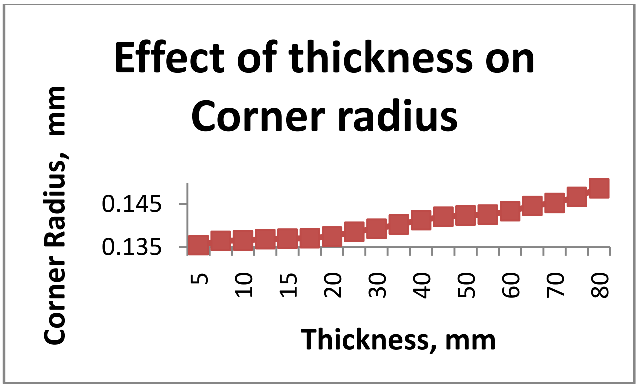

Figure 5 : Effect of workpiece thickness on corner radius

Fig.5. shows the variation in corner radius with the increase in thickness of workpiece. The curve shows an increasing trend in corner radius with increase in thickness of the workpiece. The plot shows that the spark gap increases with increment in workpiece thickness. The increase in gap may be due to the spark jumping longer because of high energy generated at high current values, is required to machine the job of higher thickness causing deeper cutting, though the rate of change is proportionate with respect to the job thickness. The profile geometry/contour of the corner radius generated can be similar to that of cross-section of the wire used for machining. From the plot, corner radius that can be achieved can be predicted while machining a particular workpiece thickness at optimum cutting parameters. The parameters can be set even for the required corner radius on a given job thickness from the database built while optimizing the parameters.

c) Machinability Index

The data for machining 5mm thick workpieces of Mild steel, HSS, HC-HCr steel, En24 steel, Stainless steel, Copper, Brass, Graphite, Tungsten-carbide and Titanium are adopted from the literature[4, 5, 10-12], and Inconel X-750 are considered from the present research work. The machinability index is calculated for all these materials and tabulated as below.

Table 1: Machinability Index

S.No.	Material, (5mm thickness)	Cutting speed, (mm/min)	Machinability Index
1	Mild steel	3.10	1.000
2	HSS	3.44	1.207
3	HC-HCr steel	2.20	0.752
4	EN24 steel	2.67	0.827
5	Stainless steel	3.00	0.985
6	Copper	2.80	1.253
7	Brass	7.80	2.560
8	Graphite	1.60	0.616
9	Tungsten carbide	1.40	0.474
10	Titanium	4.11	1.412
11	Inconel X-750	3.84	1.324

II. Conclusion

The influence of machining parameters like Current and Workpiece thickness with respect to the accuracy criterion such as cutting speed and spark gap are determined. A better control on machining accuracy can be achieved in comparison with earlier researchers by controlling the primary parameter "current" in turn Power. The results are useful in setting up the parameters required for accurate cuts on Inconel X-750 workpieces of any size ranging between 5 and 80mm. The appropriate machining parameters can be chosen depends on the availability of wire-electrodes. The mathematical relation developed and the plots are much more beneficial in estimating the spark gap and also to achieve high cutting accuracy for any given workpiece thickness within the working range of the select machine. The modern industrial applications like tool and die manufacturing units may make use of these results in order to optimize the use of Wire EDM resources in more efficient manner than the past.

Student fraternity, Researchers, Manufacturing industry can refer the machinability index developed out of this research to have an overall understanding about various challenges like the degree of difficulty or ease while dealing with the machining of different materials.

The findings of the present work will open up new insights into the fundamental and applied researchers in the WEDM area for better understanding of the technology, and also useful to the manufacturing industry and tool rooms for taking up a quantum leap from the present day needs of machining of the conductive materials irrespective of their metallurgical properties.

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