EXPERIMENTAL INVESTIGATION AND DEVELOPMENT OF MATHEMATICAL CORRELATIONS OF CUTTING PARAMETERS FOR MACHINING GRAPHITE WITH CNC WEDM

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Abstract: *The Wire cut electrical discharge machining is found to have tremendous potential in the present day metal cutting process, for achieving improved geometric features of work pieces, dimensional accuracy, surface finish etc. Improving the productivity in CNC WEDM depends solely on optimization of various process parameters viz... discharge current, thickness etc. Thus the present work is aimed at experimental evaluation of those machining parameters for different sizes of Graphite which is a prominent electrode material. Further the effect of these parameters on cutting speed, spark gap and material removal rate is investigated and best suited values are obtained for stable and controlled machining with least wire breakage. Based on the experimental results, empirical correlations are established and validated to evaluate the above parameters analytically for different work piece sizes. The correlations are found useful for finding the best suited discharge current, spark gap, cutting speed and cutting time under various cutting conditions. The results are represented in graphical form also.*

Key Words: *WEDM, Cutting speed, MRR, Spark gap, Mathematical correlations*

INTRODUCTION

The Wire-cut EDM is the focus of researchers and engineers especially in the field of dies, moulds, precision manufacturing, contour cutting etc. Any complex shape can be generated easily with higher accuracy and surface finish, using CNC WEDM, which is not possible to be achieved by normal EDM process. The Wire- cut EDM is precision machining process for micro machining of micro structures, such as high aspect ratio micro holes, slots and moulds. The basic characteristic of the wire cut -EDM process is similar to that of the EDM process with the main difference being in the size of the tool used, the power supply of discharge energy and the resolution of the X, Y, and Z axes movement. In order to improve the process control, it is very important to understand the effect of critical machining parameters involved in the material removal mechanism. One of the important characteristics associated with the removal mechanism of the formation of crater are diameter, spark gap, cutting speed and material removal rate. In the past many studies have clearly shown that the melting and vaporization are the causes of removal of material. The scope of development of indigenous software has further strengthened the process technology even in correcting the geometrical and technological data for improving work piece accuracy features[1].One of the main advantages of this process is that a very small internal corner radius can be achieved because the tool used is a very thin wire[2]. This machine facilitates the manufacturing engineers to cut hard to machine materials with high accuracy, surface finish, close tolerances and contours[3]. The WEDM is a specialized field of EDM, which requires an extensive research. An analysis of effects of various process parameters is required for achieving improved machining characteristics[4].There is an immediate need to develop Mathematical relations for successful utilization of the process with high productivity. The parameters which demand attention for the purpose of analyzing their significant effects on the machining characteristics include discharge current gap voltage, wire material, wire tension, wire speed[5-7] etc.

EXPERIMENT

Figure 1 shows the schematic view of the experimental set up. Based on the work done by the previous researchers[5,6], the best fit parameters as shown below are set on the machine before cutting:

Machine	: ELCUT 234
Dielectric	: De-ionized water
Dielectric conductivity	: 38 mohs
Wire Tension	: 70 N
Wire velocity	: 3.4 m/min
Wire diameter	: 0.25mm
Wire material	: 66-34 Brass
Gap voltage	: 80 V

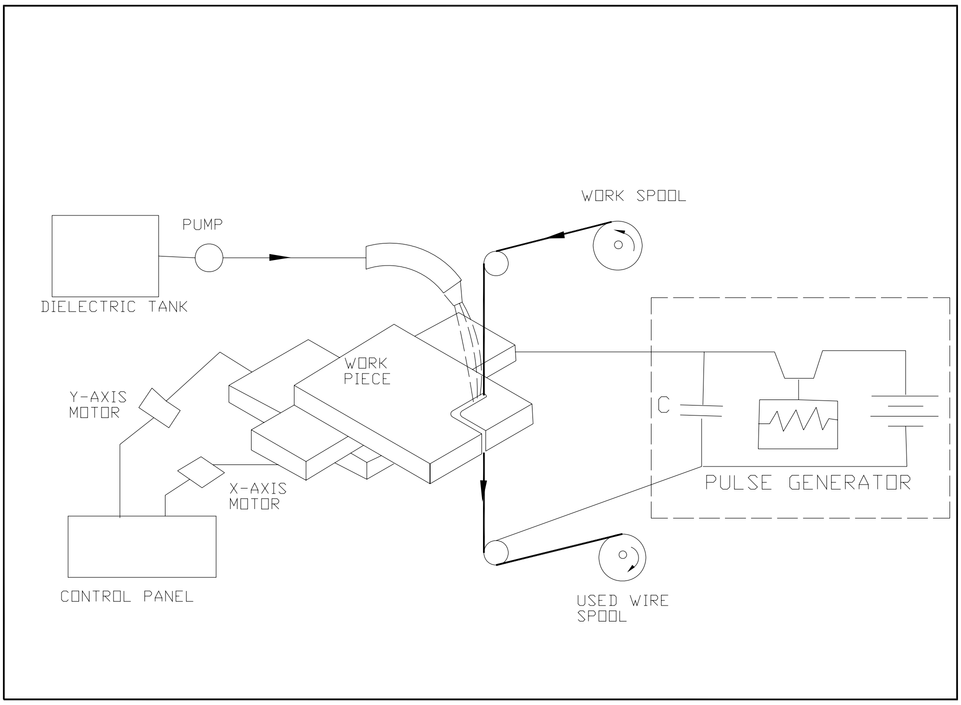

Figure 1. Schematic view of Wire cut EDM

Figure 2. Photographic view of experimental setup

Using CNC part programming, rectangular slot of 4mm x 6mm and L shaped slot is cut on 5mm thick Graphite work piece by varying discharge current for 5 times. The L- slots are tested for spark gap using shadow graph technique and micro scope. The photograph of experimental setup is shown in Fig. 2. The rectangular slots are tested for surface roughness values using Tally surf. From this, the best value of discharge current is recorded for stable machining with maximum cutting speed and minimum wire breakage. At this value of current, the best value of cutting speed, spark gap is recorded and material removal rate (MRR) is computed. The experiment is repeated for 19 different work piece thicknesses varying from 5mm to 80mm. The best value of discharge current obtained for each thickness and the corresponding cutting speed, spark gap and material removal rate (MRR) are represented in graphical form.

The experimental data thus obtained is subjected to statistical analysis (ANOVA) using the soft ware Origin 8.0. The best fit curve to suit the data is also obtained in the form

$$y = A_2 + \left\{ \frac{A_1 - A_2}{\left[1 + \exp\left(x - x_0\right)/dx\right]} \right\}$$

and the mathematical correlations for this best fit curve are taken in to consideration.

RESULTS AND DISCUSSIONS

The variation in the discharge current with the increase in work piece thickness is obtained and is shown in Fig. 3.

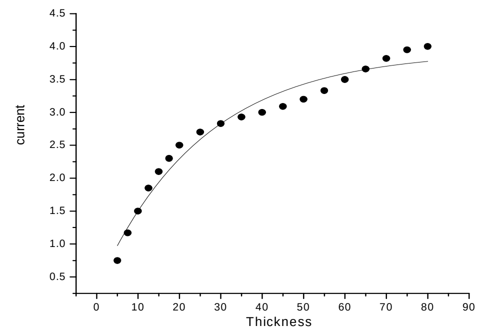

Figure 3. Effect of discharge current on thickness

For a specified set of machining conditions it is observed that with increase in thickness, the required current also increases. This is attributed to the high amount of energy required for high thickness job in which machining is possible only by increasing the current. How ever the rate of current rise is found decreasing with increasing thickness. Thus this plot is useful to extract suitable minimum discharge current required for machining of any thickness Graphite work piece with in the machine working range. By interpolation of the obtained data the equation for the best fit curve is obtained as

$$I = 3.92 - \left\{ \frac{7456.62}{\left[1 + \exp\left(T + 193.05\right)/25.28\right]} \right\} \quad (1)$$

where I = discharge current, amp
T = thickness, mm

Table 1 gives the statistical data generated during the ANOVA (error analysis) done with Origin 8.0soft ware while developing the above equation. The correlation co-efficient R^2 value of 0.96952 is obtained which indicates the fitness of the curve and the standard deviation as 0.179.

Table 1. Statistical data for Fig. 3

Number of points	19	A1	-7452.7
Degrees of freedom	15	A2	3.92677
Reduced Ch-sqr	0.03222	xo	-193.05
Residual sum of squares	0.48325	dx	25.28
R Value	0.98464		
R-square(COD)	**0.96952**		
Adj.R-square	0.96342		
Root-MS(SD)	**0.17949**		

Figure 4 shows the effect of thickness on cutting speed for various sizes of the work pieces. The plot indicates that as thickness of the work piece increases the cutting speed decreases rapidly. For thickness beyond 70mm the cutting speed almost remains constant. If the thickness increases, the volume of metal to be removed increases which demands more energy and it may become a machine constraint. At the same time the spark is jumping to the sides of the wire causing more width of cut, reducing the cutting speed. The data thus obtained is subjected to interpolation and the best fit curve correlation is obtained in the form

$$Cs = 0.25 - \left\{ \frac{6001.31}{\left[1 + \exp\left(T + 79.09\right)/9.94\right]} \right\} \quad (2)$$

where Cs = cutting speed, mm/min.

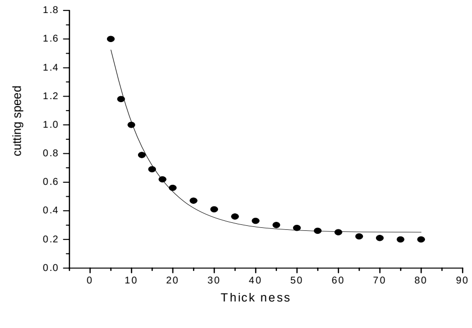

Figure 4. Effect of cutting speed on thickness

Table 2 gives the statistical analysis, showing R^2 value as 0.98731 which envisages the fitness of the curve. The standard deviation for this plot is 0.047. From this plot or from the above mathematical correlation, the cutting speed can be predicted for any size of work piece to be machined. This is also useful in evaluating the machining time and cost.

Table 2. Statistical data for Fig. 4

Number of points	19	A1	6001.56
Degrees of freedom	15	A2	0.25004
Reduced Ch-sqr	0.00225	xo	-79.089
Residual sum of squares	0.03374	dx	9.9438
R Value	0.99364		
R-square(COD)	**0.98731**		
Adj.R-square	0.98478		
Root-MS(SD)	**0.04743**		

The variation of spark gap with the increase in thickness of work piece is depicted in the Fig. 5. The curve shows an increasing trend in spark gap with increase in thickness of work piece. This may be due to the property of spark, which jumps longer at higher current values an essential requirement at higher thickness. However the rate of variation is low for thickness beyond 60mm.

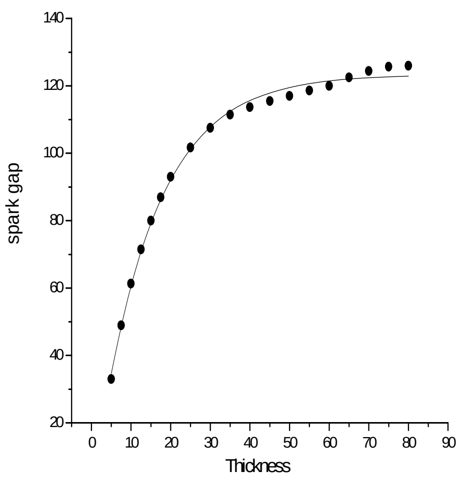

Figure 5. Effect of spark gap on thickness

The best suitable curve is drawn and error analysis is carried out using the same Origin 8.0 soft ware. The mathematical correlation obtained is

$$SG = 123 - \left\{ \frac{1416216.65}{\left[1 + \exp\left(T + 100.93\right)/14.361\right]} \right\} \quad (3)$$

where *SG* is the spark gap in micro meters.

Table 3. Statistical data for Fig. 5

Number of points	19	A1	-141493
Degrees of freedom	15	A2	123.38
Reduced Ch-sqr	3.4112	xo	-100.93
Residual sum of squares	51.168	dx	14.36
R Value	0.99818		
R-square(COD)	**0.99637**		
Adj.R-square	0.99564		
Root-MS(SD)	**1.8469**		

The statistical analysis presented in Table 3 shows the values of R^2 = 0.9963 and standard deviation as 1.8469 are obtained and are tabulated in Table.3. The correlation is useful in finding the spark gap in turn cutting width, to compute the MRR and program the wire off set during CNC part programming, and hence higher accuracy can be achieved.

The change in MRR with increase in thickness is shown in the Fig. 6. The plot shows a constant rise with a positive slope. This may due to the increase in cutting speed and spark gap.

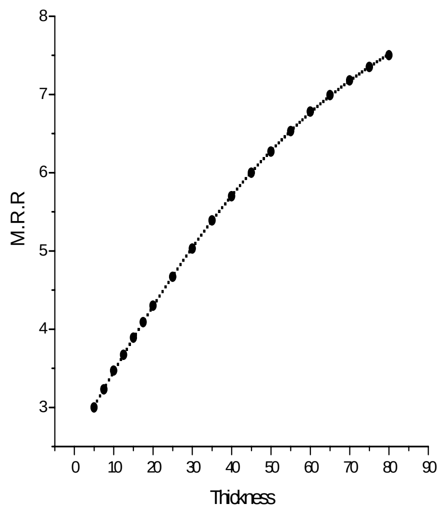

Figure 6. Effect of MRR on thickness

The best fit curve is taken along with mathematical correlation as

$$MRR = 8.9 - \left\{ \frac{16.38}{\left[1 + \exp\left(T + 19.05\right)/41.69\right]} \right\} \quad (4)$$

where MRR is material removal rate, mm^3/ min.

The statistical data obtained in the error analysis (ANOVA) gives R^2 = 0.9999 which indicates the fitness of the curve and correlation. The standard deviation obtained is 0.0095. The results of the analysis are presented in Table 4. The above correlation is be useful in determining the maximum achievable MRR and can also be used for cutting time and cost calculations.

Table 4. Statistical data for Fig. 6

Number of points	19	A1	-7.4877
Degrees of freedom	15	A2	8.9062
Reduced Ch-sqr	9.078E-5	xo	-19.058
Residual sum of squares	0.00136	dx	41.698
R Value	0.9999		
R-square(COD)	**0.9999**		
Adj.R-square	0.9999		
Root-MS(SD)	**0.00953**		

CONCLUSIONS

The influence of parameters, like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, material removal rate are determined. The results are useful in setting the parameters required for quality cuts on Graphite. Suitable parameters can be selected for machining with the available wire. The mathematical correlations developed are much more beneficial to estimate the cutting time, cost of machining and accuracy of cutting for any size of the Graphite work piece within the machine operating range. These results will be useful to make the Wire EDM system to be efficiently utilized in the present day die and tool-manufacturing units and to make electrodes for EDM and ECM processes.

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