Amirkabir University of Technology
(Tehran Polytechnic)
Vol. 45, No. 2, winter 2013, pp. 37-39

Amirkabir Journal of Science & Research (Mechanical Engineering)
(AJSR - ME)

Analysis of Residual Material and Machining Error on Straight and Corner Curved Paths in Roughing of WEDM

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(Received 30 Oct 2011, Accepted 11 Jan 2014)

ABSTRACT

Wire electrical discharge machining (wire-EDM) is able to generate delicate and complex shapes on hard materials which are difficult to cut. Inaccuracy in the cutting of small radius curved corners is one of the major problems in this process. In the present paper, corner radii machining errors have been investigated. Experiments are designed using the Full Factorial Method for roughing operations by considering frequency of discharges, wire tension and radius of curvature as variables, and the residual material on straight and curved paths as the output parameters. Practical works are implemented on tool steel 1.2510. By employing statistical techniques for analysis and by calculating variable side gap on curved corners, the machining error is obtained for 150, 300 and 450 µm radius curvatures. Results show that the thickness of residual material left on the workpiece on straight and curved paths can be the same if the cutting path on curvature is corrected according to the findings of this paper.

KEYWORDS

Wedm, Machining Error, Corner Radii, Residual Material, Wire Deviation.

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1- Introduction

Wire EDM is a complicated machining process with a random nature. The performance of WEDM, especially in achieving dimensional and geometrical accuracy, depends highly on machining parameters. To investigate accuracy, the cutting path should be analyzed. Wire moves on a pre-determined cutting path which is defined in terms of points, lines and curves. Its motion is controlled by advanced control systems to retain the size of frontal and lateral gaps between the wire and work-piece.

In spite of high accuracy of control systems, it is very difficult to generate accurate arcs when the arc diameter is less than 2 mm. There is always a high risk of wire vibrations or deflections and consequently, deviations from the pre-defined cutting path. The reason goes back to the inevitable unbalanced process forces on flexible wire (such as electrostatic, electromagnetic, electrodynamic and plasma explosion forces; and dielectric pressure), especially on small arcs. The maximum difference between programmed and deflected-wire paths is defined as wire-lag.

Among initial investigations about the error of machining of the corners, study of Dekeyser and Snoeys (1989) is remarkable. They found that the errors in corners were due to wire lag, wire vibrations and possibly increased discharge at corners [1]. Some researchers attempt to modify cutting parameters, such as discharge power; thus the wire deflection could be significantly reduced and geometrical and dimensional accuracy and straightness of the work-piece wall could be increased [2]. The main drawback here is the increase of machining time. In order to increase accuracy Obara *et al.* [3] propose a combination of power control with path correction in corners at the roughing stage. In this approach, power control is implemented to reduce wire bending, while the path regeneration is to compensate the errors. They claim that this method requires the least time for corner machining. In another work, Obara *et al.* [4] investigate several controlling methods for reducing machining time in the corners and finally suggest a combination of increase in the off-time pulse duration, control of servo voltage, and path compensation techniques. The present paper investigates relations between accuracy and material removal of small-radii corner in roughing. Also, the effects of roughing parameters on residual material on straight path and small-radii convex corners (discharge frequency and wire tension (in roughing) on residual material on straight and convex curved paths) are examined.

2- Methodology

Experiments are performed on 1.2510 (AISI: O1) tool steel with 54×59×9 mm^3 dimensions. Charmilles Robofil 200 wire cut machine and SW25X wire (with 0.25mm diameter) recommended by Charmilles are used for cutting. The pieces are adjusted accurately on the machine table with the least distance of lower and upper machine jaws from the work-piece bottom and top surfaces, respectively. The ambient conditions are kept constant and steady. After cutting the pieces, measurements are performed by a 0.001 mm resolution mechanical comparator and standard gauge blocks under thermally stable conditions.

Table 1 shows the recommended values of the machine manufacturer for one-stage cutting of a 10mm thick steel piece [12]. Among WEDM parameters, discharge frequency and wire tension can be used as input variables for controlling the explosion force and wire bending, respectively. Therefore, in this paper, the effects of variation of f (frequency), w_b (wire tension) and R (corner radius) on y_0^{st} and y_0^{cr} are investigated using the values given in Table (1).

Table (1)
Levels of variable parameters used in the experiments. Bold values are recommended by the manufacturer.

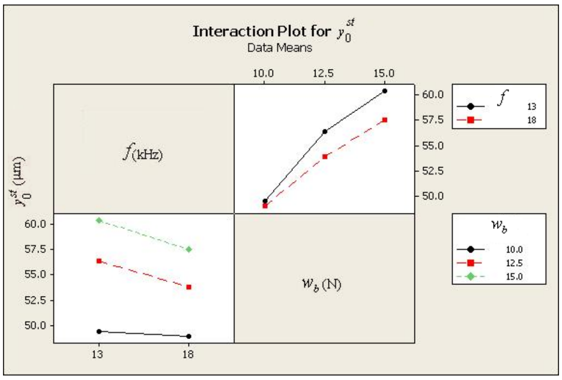
Parameters	Levels	Parameters values		
f (kHz)	2	13	**18**	-
w_b (N)	3	**10**	12.5	15
R (μm)	3	150	300	450

In this study, Design Of Experiments (DOE) methodology is applied for preparing required data. Based on the full factorial method, DOE prepares the plenary data of a process.

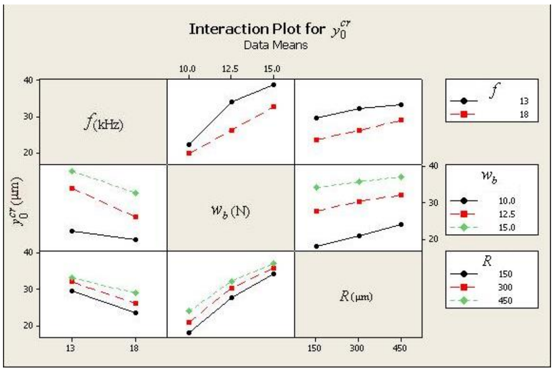
3- Result

Experimental results show the effects of discharge frequency and wire tension on y_0^{st} and discharge frequency, wire tension and corner radius on y_0^{cr} .

By increasing the wire tension and decreasing the frequency, the residual material for both cases is increased. The wire tension is always the most effective parameter on the residual material. Also, variation of corner radius has a little influence on residual material in curved paths. When the wire tension is at its maximum and the frequency of discharges is at its minimum, the residual material will be at its maximum as is shown in following figures.



Effects of the interaction of frequency and wire tension on residual material in straight path y_0^{st}



Effects of interactions of parameters on y_0^{cr}, roughing convex corner

Calculating the lateral spark gap for various experiment settings in straight path cutting also shows that the lateral spark gap can be decreased by increasing the frequency and decreasing the wire tension. On a curved path, spark gap is variable for various points of the wire perimeter since these points have different linear feed speeds. The residual material on straight and various arc paths will be the same if curved paths are modified using the experimental deviations.

Higher frequency (number of pulses per unit time) results in higher material removal rate and reduced residual material. On the other hand, when the tension is increased, the residual material on the straight and curved paths (y_0^{st} and y_0^{cr}) is also increased. Increasing corner radius causes a decrease in path curvature and results in increasing the residual material on the curved path.

4- Conclusions

1- By increasing the wire tension and decreasing the frequency, the residual material for both cases is increased. The wire tension is always the most effective parameter on the residual material. Also, variation of corner radius has a little influence on residual material in curved paths. When the wire tension is at its maximum and the frequency of discharges is at its minimum, the residual material will be at its maximum.

2- The ratio of residual materials on straight and curved paths shows that the minimum error (defined as the difference between residual material on straight and curved paths) happens under minimum level of frequency (13 kHz) and maximum level of wire tension (15 N).

3- Calculating the lateral spark gap for various experiment settings in straight path cutting also shows that the lateral spark gap can be decreased by increasing the frequency and decreasing the wire tension.

4- In curved corner cutting, in addition to the variable gap error, there is an extra error due to deflection and deviation of the wire into the path inner arc. Combination of these two effects decreases the residual material on the convex arc and increases residual material on concave arc, compared to the straight path.

5- Total convex arc machining error is calculated for each experiment setting using the residual materials on straight and convex curved corners. The residual material on straight and various arc paths will be the same if curved paths are modified using the experimental deviations.

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