CRATER TO PULSE CLASSIFICATION FOR EDM WITH THE RELATIVE ELECTRODE TO THE WORKPIECE MOTION

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SUMMARY

This paper focuses on EDM sinking experiments with the relative motion of the electrode to the workpiece in order to examine the produced surface properties. The crater features were analyzed by microscopy which has enabled us to classify them into three categories, according to the crater shape and size. In addition voltage and current pulses and their attributes were captured by the high frequency oscilloscope. By means of inductive learning we obtained the performance rules predicting the corresponding crater classes to the specific pulse. Migration phenomena was detected due to relative motion at longer pulse duration. We have examined the possibility of technological application of the EDM process with the relative motion by means of removal rate and roughness at different working conditions and relative speed.

KEY WORDS : *crater, inductive learning, classification, technology*

1. INTRODUCTION

The EDM process generates the workpiece surface by discharges occurring in the gap between the electrode (tool) and the workpiece. The third element is the dielectric which flushes the working gap. Material removal is effected on atomic scale by increasing internal energy of atoms. As a result the processing unit event-the crater is produced. The size and the shape of the crater depend on the machine setting and process control. The highly unpredictable gap conditions causing the strong random nature of the EDM process mostly because of changeable dielectric's properties. The monodischarge as a single act of erosion was investigated by many authors to enable crater to pulse analysis. In our opinion the monodischarge analysis gives very few information about real EDM process mostly because of random gap conditions defined by the quality and the state of the dielectric fluid. In this paper we present an attempt to integrative approach, relating the pulse discharge to the corresponding crater, by means of the inductive learning (IL) technique /1,2/. EDM experiments with the rotating electrode have been carried out in order to enable crater to pulse classification and to examine the distinction between steady and moving electrode /3,4,5/.

2. CRATER TO PULSE EXPERIMENT

The most important problem in basic EDM investigations is defining experimental conditions. The greater part of the investigations of discharges are based on the mono discharge phenomena which disable the insight into the random EDM process. The basic scope of this research is to define relations between electrical characteristic of pulses and the produced craters. The experiment was carried out on an Ingersoll ED sinking machine with the rotating electrolytic copper electrode (d=0.5mm.) over the workpiece made of tool steel (d=150mm) (Fig.1.). The electrode velocity was in the range of the velocity in ED grinding operation (v=30-180m/min). In order to facilitate the distinction of successive craters relatively long pulse duration t_i and pulse interval t_o have been selected (Table 1.). In such working conditions we expect a rather strong effect of discharge migration on the crater topography.

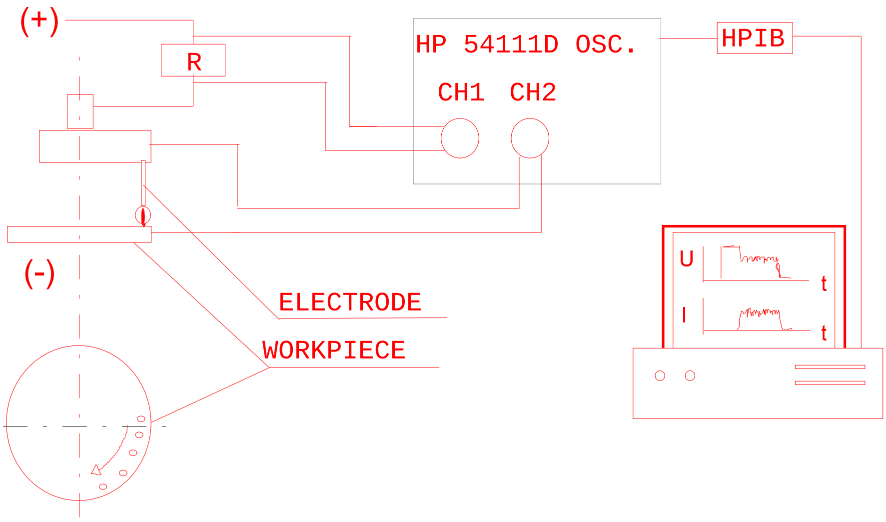


Figure 1. Crater to pulse classification experiment

Table 1. EDM working conditions for craters' classification

Regime	t_i/µs/	t_o/µs/	i_e/A/	u_i/V/
1	440	60	13	140
2	255	60	13	140
3	125	60	13	140
Electrode: electrolytic copper (+) Workpiece: tool steel (-) Dielectric fluid: EROZOL 70				

- t_i	/µs/	pulse duration
- t_o	/µs/	pulse interval
- i_e	/A/	maximal discharge current
- u_i	/V/	open circuit voltage

3. CRATERS' CLASSIFICATION

The voltage and the current probe were mounted and the train of ten successive signals was fed into the fast (2GHz) two channel digital oscilloscope HP 54111 (Fig.1.). The sampling interval of 1 µs with the resolution of 1.5V and 0.47A has been chosen so as to enable the detection of different characteristic voltage and current attributes as presented. The pulse data (trains of 5000 points representing 5000µs) are stored in the computer system for further evaluation. We have chosen the following attributes of pulses to distinguish them and evaluate with inductive machine learning:

- t_e	/µs/	discharge duration
- u_e	/V/	average discharge voltage
- min(u_e)/V/		minimum discharge voltage
- max(u_e)	/V/	maximum discharge voltage
- std(u_e)	/V/	standard deviation of u_e
- i_e	/A/	average discharge current
- min(i_e) /A/		minimum discharge current
- max(i_e)/A/		maximum discharge current
- std(i_e) /A/		standard deviation of i_e
- P	/W/	average discharge power
- W	/J/	average discharge energy

- u_e/i_e /Ω/ average gap resistance in discharge

Photographs of craters captured by high frequency digital oscilloscope were taken both by optical and scanning electron microscope in order to enable visual classification. Craters have been ranged into three classes: class A is SMALL, class B is LARGE-FINE and class C is LARGE-ROUGH (fig.2.).

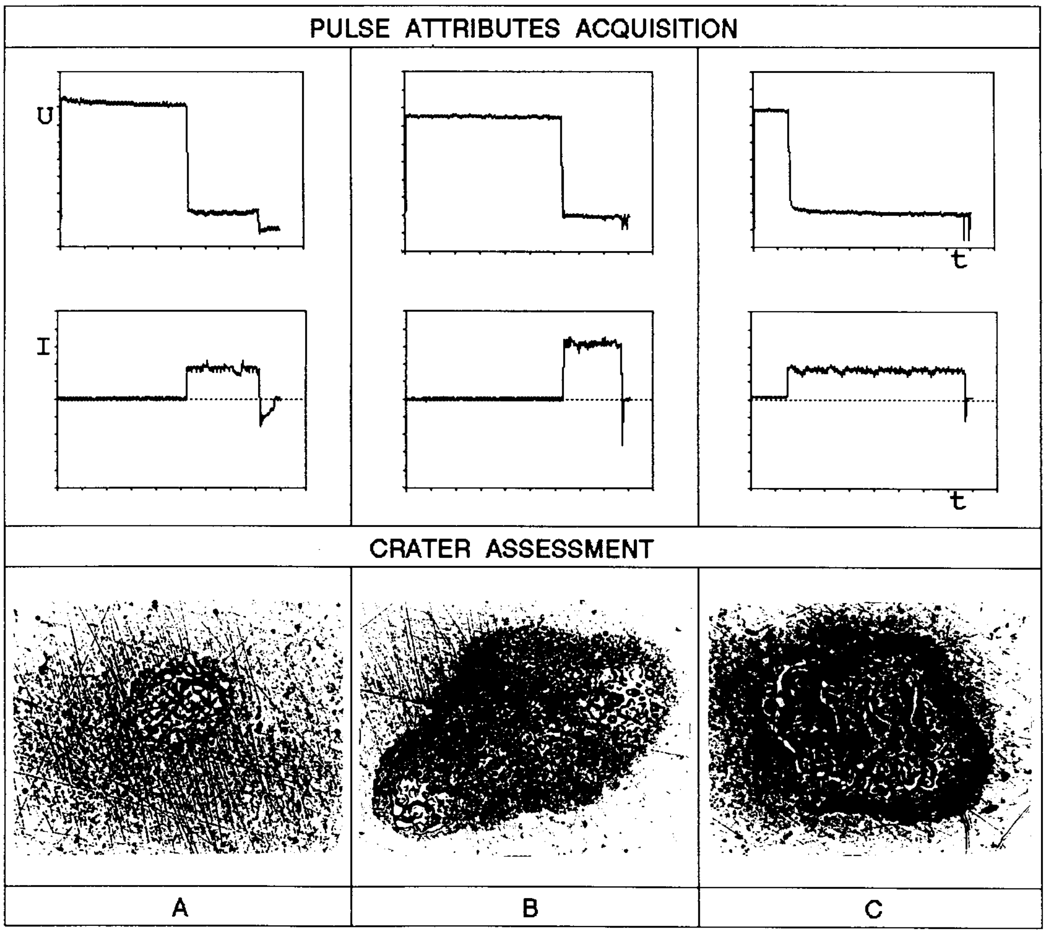
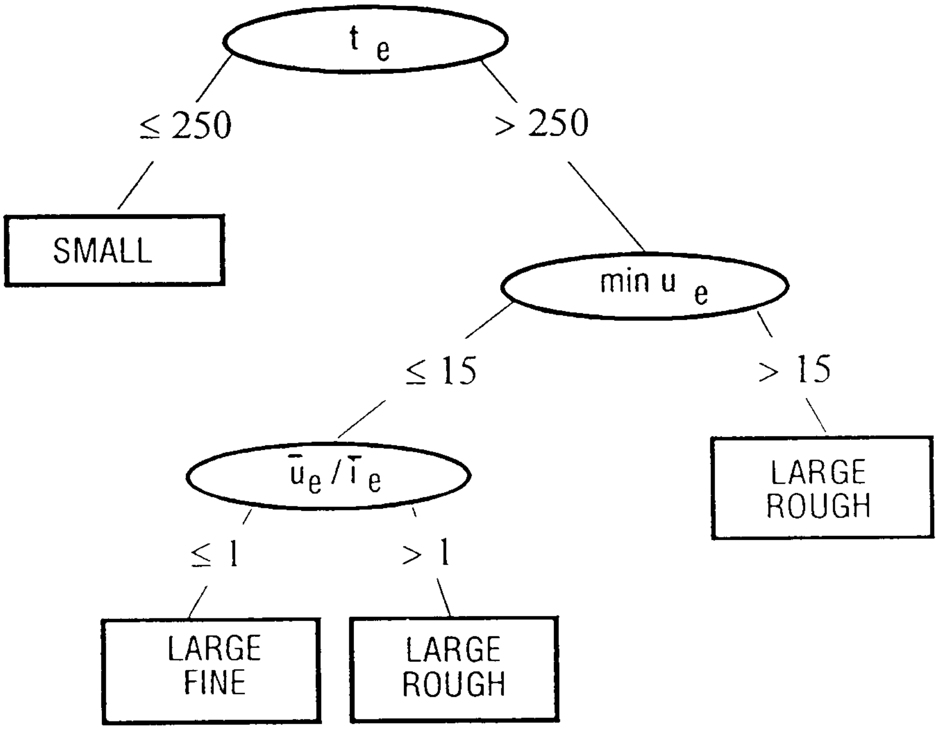


Fig.2.: Visual craters' classification

Assistant Professional program was applied for learning crater features from pulse attributes which were evaluated from voltage and current signals captured by oscilloscope. The program belongs to the family of machine learning systems TIDIDT (top-down induction of decision trees)/9/. It extracts the knowledge domain in the form of a decision tree from a set of a training examples specified by attributes values and classes. A decision tree is built recursively using entropy as a measure of the most informative attribute. In the induced tree nodes denote attributes and leaves are labeled as classes. We have given the training set of 84 examples made with regime 1 (table 1) and Assistant Professional induced the decision tree (fig.3.).

The attribute appearing as the most informative at the root of the decision tree is the discharge duration t_e. The tree splits in two branches. Pulses with lower discharge duration generate small craters while those with higher values generate large craters which is consistent with the EDM theory and practice. Whether the large crater is fine (shallow) or rough (deep) depends on two other attributes showing up in the nodes of the second subset of the tree. Pulses with higher value of the minimum instantaneous voltage produce large and rough craters. On the other side whether pulses with lower instantaneous voltage produce fine or rough craters depends on the ratio between average pulse voltage and average pulse current representing the resistance of the discharge plasma channel. In case of lower resistance the plasma channel is more susceptible to migration and energy dissipation resulting in large and fine crater (fig.2.).



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if $t_e \le 250$ then class A = SMALL
  else
    if min $u_e \le 15$ then
      if $u_e/i_e \le 1$ then class B = LARGE-FINE
      else class C = LARGE-ROUGH
    else class C = LARGE-ROUGH
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Fig.3.: The decision tree predicting the crater features

The induced decision tree enables classification of the new classes with unspecified classes so it establishes the relations between pulse characteristic and crater's shape. The average classification accuracy of the procedure applied to new data (i.e. the ratio of correctly classified testing examples) was estimated to be 69,7 %. This result was acquired through a series of 10 tests in each of which 70 % randomly selected examples from the original set were used for learning and the remaining 30% for testing. The attained classification accuracy is satisfactory having in mind the strong random nature of the EDM process.

4. THE COMPARISON BETWEEN EDM PROCESS WITH THE STEADY AND THE MOVING ELECTRODE

In some special cases electro discharge processes make use of orbital and planetary motion of the electrode as a tool to achieve better working results. As a technological effect the motion of electrode means improved flushing conditions in the working gap and decreased possibility of undesirable pulses.

The cooling effect of the dielectric fluid is distinctive too. Lower temperature of the dielectric fluid means lower portion of arcs. The rotation of cylindrical electrode decreases the number of electrodes needed when producing cylindrical holes.

The scope of our research is to establish the distinction between both EDM with steady electrode and with relative motion of the electrode to the workpiece (fig.4.) so as to examine the possibility of this EDM technology application. The experiments were conducted with rotating copper electrode d=90mm over workpieces made of tool steel with dimensions 22x15x8mm in order to enable roughness and weight measurements. We have applied 6 different working regimes at 3 velocities of the electrode (table).

Table 2: EDM working conditions for technological comparison

regime	t_i /µs/	t_o/µs/	i_e /A/	u_i/V/
r1	19	3	4.3	180
r2	39	11	4.5	180
r3	48	2	7.5	140
r4	90	10	8	140
r5	225	25	13	140
r6	450	60	31	120
Electrode: electrolytic copper (+) Workpiece: tool steel (-) Dielectric fluid: EROZOL 70				

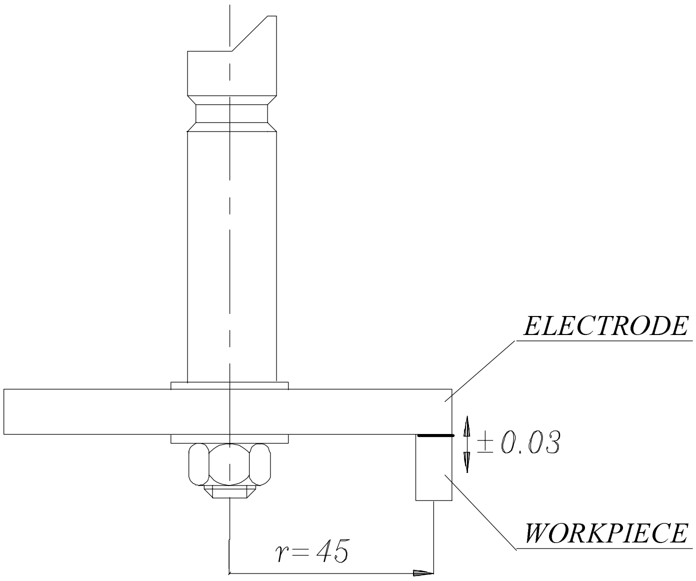

Fig.4. : The position of the electrode enabling relative motion

The craters' shapes in both processes are comparative, however there is the crater orientation in the direction of the moving electrode in the case of the relative motion. The analysis of the results confirmed the anticipation that the increasing speed of the electrode decreases removal rate (fig.5.). On the other hand the relative motion of the electrode enables larger removal rate at finer regimes which predominantly demand automatic lifting of the electrode by servosystem to improve flushing conditions in the working gap and to prevent arcs.

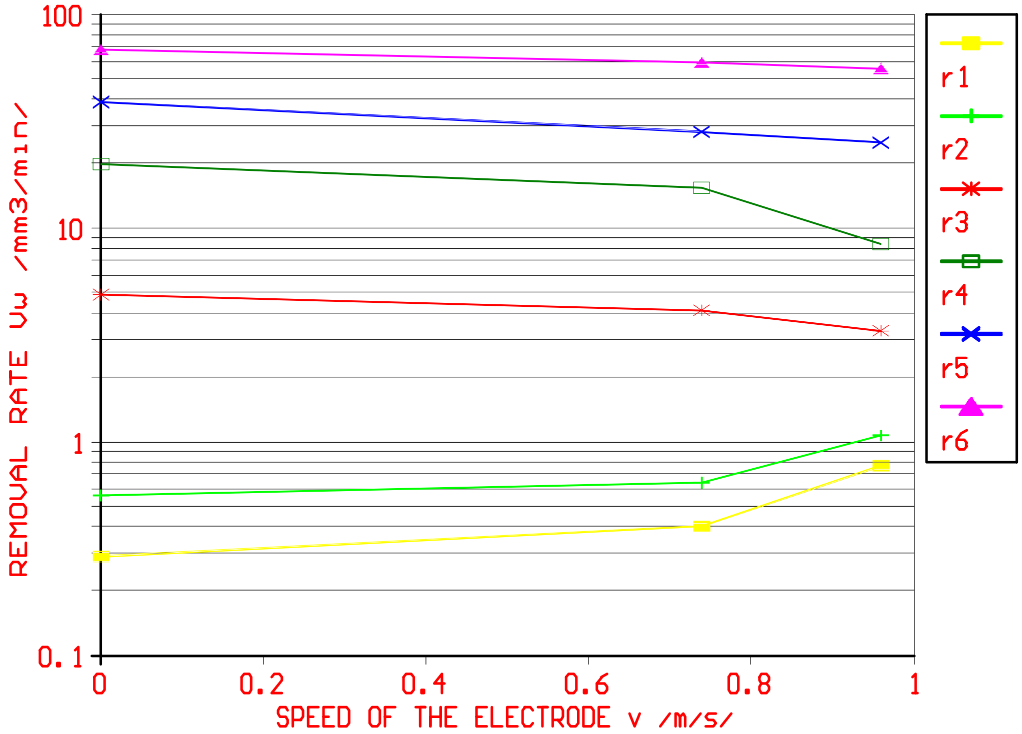

Fig.5.: Removal rate versus electrode speed

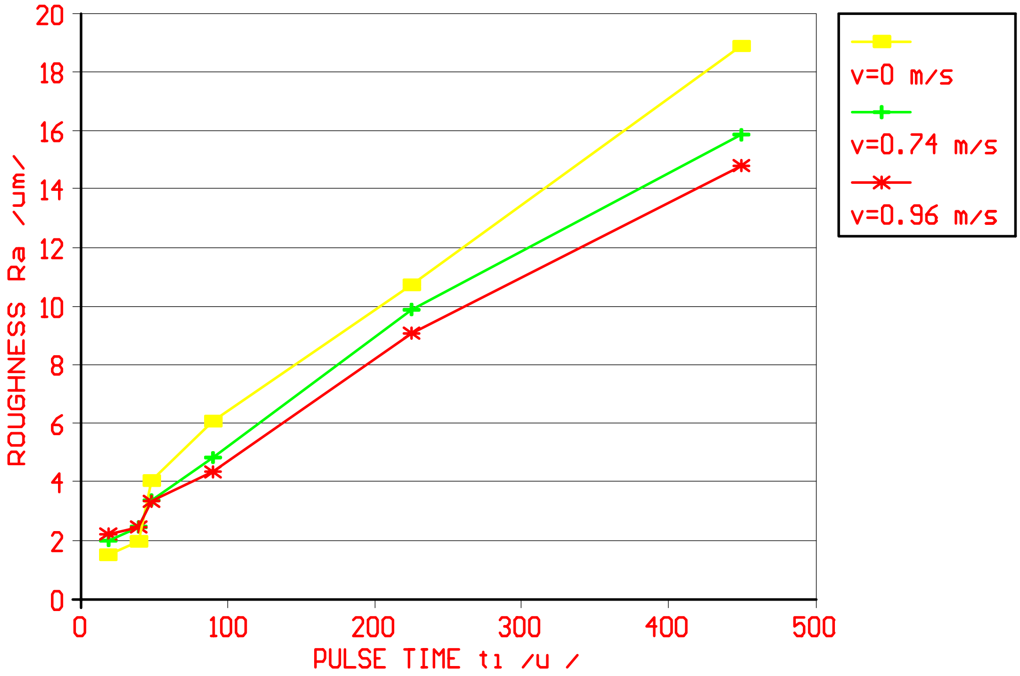

Fig.6.: Roughness of the workpiece versus pulse time

The results of the roughness measurements show that the increased electrode speed decreases surface roughness (fig.6.). That means finer surface quality at rougher working conditions. The effect of the relative motion of the electrode to the workpiece causes regular distribution of the white layer through the surface (fig.7.). Usually the white layer should be removed after EDM processing with polishing. The relative motion facilitates the removing of the white layer which enables longer tool life.

Working conditions:
t_i=450µs
t_o=60µs
i_e=31A
u_i=120V

magnification: 100x

100µm

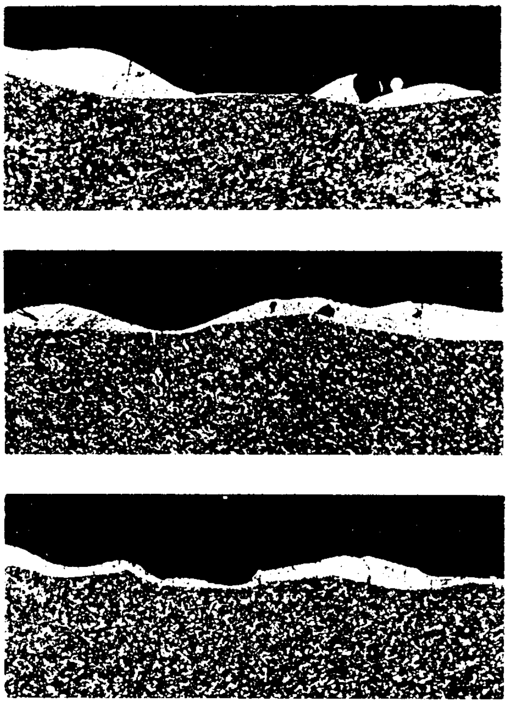

Fig.7.: Surface layers at different electrode speed

6. CONCLUSIONS

From the experimental results and the discussion, the following conclusions are drawn:

- the visual observation of the crater and its profile measurements showed obvious discharge migration due to long pulse duration t_i and mechanical disturbances of the plasma channel by the relative electrode to the workpiece motion
- the inductive machine learning approach has proved to be a promising procedure for prediction of the crater shape and size at changeable working conditions
- the relative motion of the electrode to the workpiece enables better flushing conditions in the working gap
- the produced craters are less deep and oriented in the direction of relative motion
- the surface is finer however the removal rate is decreasing with increasing speed of the relative motion
- the white layer is regularly distributed through the surface so the polishing is facilitated

7. REFERENCES

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