

THRESHOLD TECHNOLOGY AND ITS APPLICATION FOR GAP STATUS DETECTION ¹

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ABSTRACT

Process control systems of modern EDM-machines offer several opportunities for gap status detection. The method described here is the threshold technology at which the voltage course of a discharge can be classified in normal pulses, open circuits, short circuits and arcs by different voltage thresholds in combination with time recording. Especially in arc detection a new path will be treated by using a burning voltage threshold positioned slight below the effective burning voltage of a normal discharge. Its determination depending mainly from the electrode/workpiece material combination and the adjusted amperage will be described in detail. Moreover a fuzzy gap width control system will be established only based on the relative number of open and short circuits ascertained within a time period. Also in this case the threshold technology will be applied. This gets completed by a neural network. The efficiency of the different systems will be demonstrated at roughing and smoothing experiments in comparison to a ignition-delay-time (t_d) – based solution.

1. ALLEGATION OF THE VOLTAGE THRESHOLDS

The threshold technique provides an opportunity to identify the pulses of an electrical discharge by comparing characteristic voltage values with alleged voltage thresholds. From those one can deduce possibilities for a gap width controller, e. g by use of fuzzy techniques which may be combined with neural networks. Moreover it is an essential demand in EDM applications to achieve clean surfaces of the electrode and workpiece without arcing influences, especially at smoothing operations. In principle a great number of thresholds could be used. Yet, in regard to a fast signal processing, which offers the opportunity to analyse not only a single pulse at its starting phase but also its mutation to an arc during its burning phase, one should keep the number of alleged thresholds as low as possible. Therefore we only use four thresholds as demonstrated in figure 1. The below figure shows the determination of the time passed until the event.

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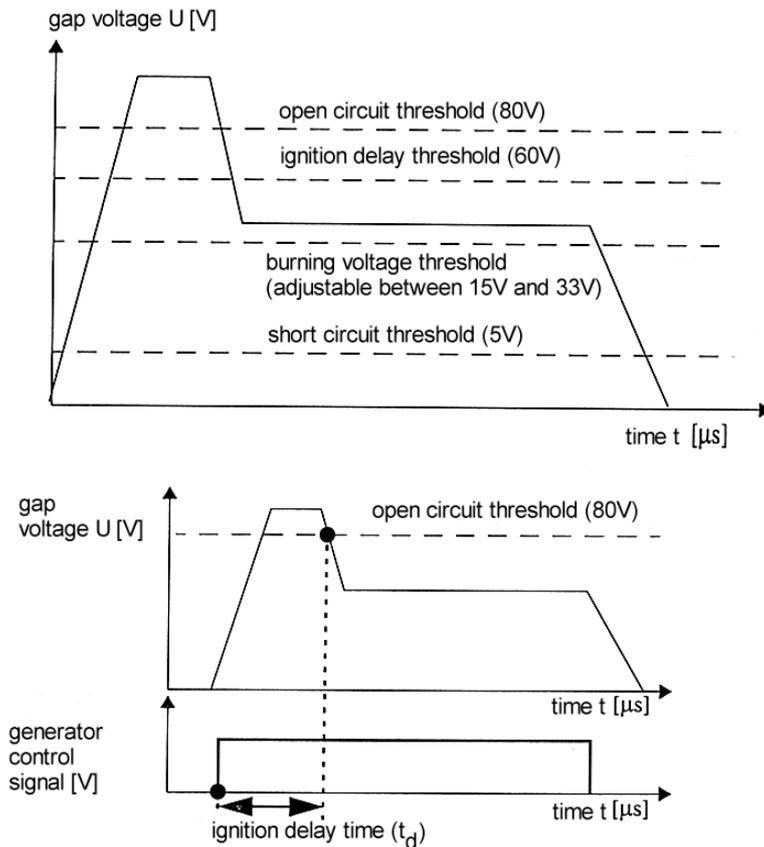


Figure 1. Thresholds detected by the gap sensor and determination of the ignition delay time

Because our gap-width controller does not work on base of ignition delay time (t_d) its determination in principle would be not necessary. We need this value only for a comparison of the efficiency of our gap width control system with the often used t_d -based controller.

The over – resp. undershooting of the threshold values gets evaluated by a measurement-FPGA (Field Programmable Gate Array). For the determination of the length of time of a high speed counter is used as shown in the below figure 1 on the example of the t_d -ascertainment. By the pulse classification the process controller gets information about the kind of discharge. In case of arcs the controller may determine the number of arcs in sequence and interrupts the clocking over a preselected period. In case arcing will not diminish a tacted flushing movement of the electrode will be released. This especially is essential for the mainly investigated unflushed erosion sinking processes.

2. DETERMINATION OF ARCS USING BURNING VOLTAGE THRESHOLD

Most of the thresholds mentioned on figure 1 are self-explanatory. Yet the determination of the burning voltage threshold used for our arc detection method must be explained in detail. Because the detection of arcs is essential for a good operating EDM-process several methods were developed for this purpose. Only some can be mentioned here:

- a. Arc detection by use of ignition delay time (used by (1), (2), (3), (4))
- b. Arc detection by undershooting the ignition voltage (used by (5), (6), (7))
- c. Arc detection by the descending flank of the ignition voltage (used by (8))
 Details can be taken from (10).
 Yet nearly all arc detection strategies are unsuitable for generators with steep ignition flanges (9) as we used. Therefore GINZEL (10) developed a new method.
- d. Arc detection by undershooting of the burning voltage threshold.
 In this connection we assume according to figure 2 that at a removal efficient pulse the burning voltage steady remains above a suitable alleged burning voltage threshold.

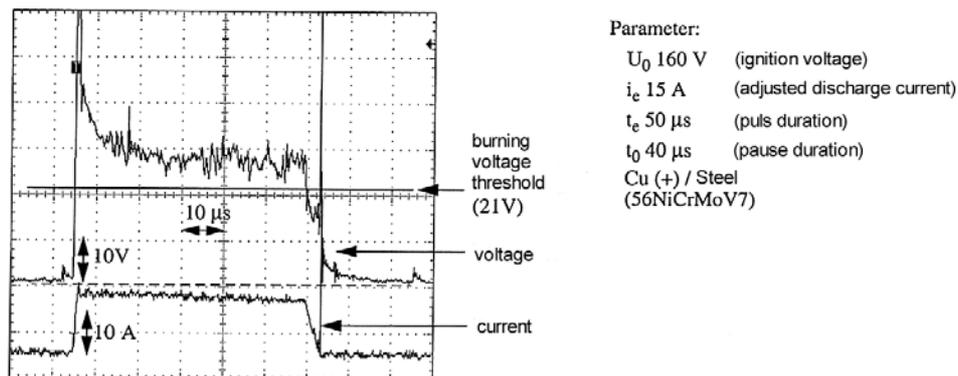


Figure 2. Course of burning voltage and current at a removal efficient pulse

In contrast to that a discharge will be recognized as an arc if the burning voltage undershoots this threshold. This may occur immediately after ignition but also during the burning phase. The latter will be demonstrated in figure 3 at a series of pulses recorded at sparc erosion machining of sintered metal carbide. In this case the undershooting leads to a spontaneous cut-off of the current during the ongoing discharge. This spontaneous cut-off guarantees in every case a surface totally free from hot spots.

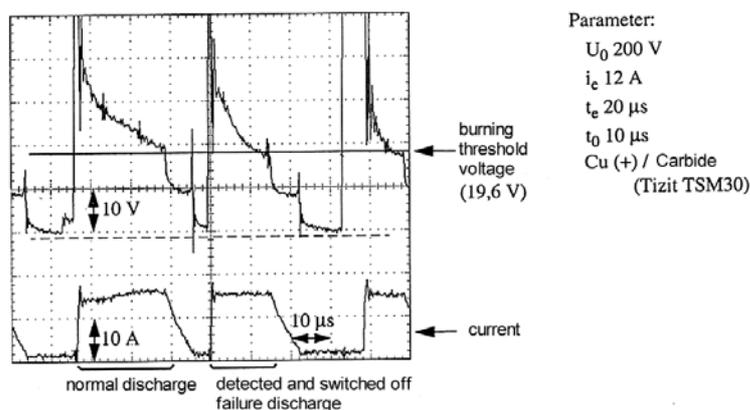


Figure 3. Detection of failure discharges at carbide erosion

3. DETERMINATION OF THE BURNING VOLTAGE THRESHOLD

The optimal value of the burning voltage threshold must be determined by removal experiments. It depends on the material combination (electrode/workpiece) and on the adjusted amperage. Therefore its determination requires a greater number of experiments. Figure 4 demonstrates the experimental approach. If the adjusted burning voltage threshold is too low only a small number of faulty discharges will be detected. This leads to a fluttering control behaviour which affects the removal rate in a negative way. If the threshold value is too high the number of switch-offs also is too high. This likewise leads to a reduction of removal, because augmented regular discharges will be cut off. In the demonstrated case the optimal threshold value is located at 22.25 V. Aside the achieved electrode wear is depicted.

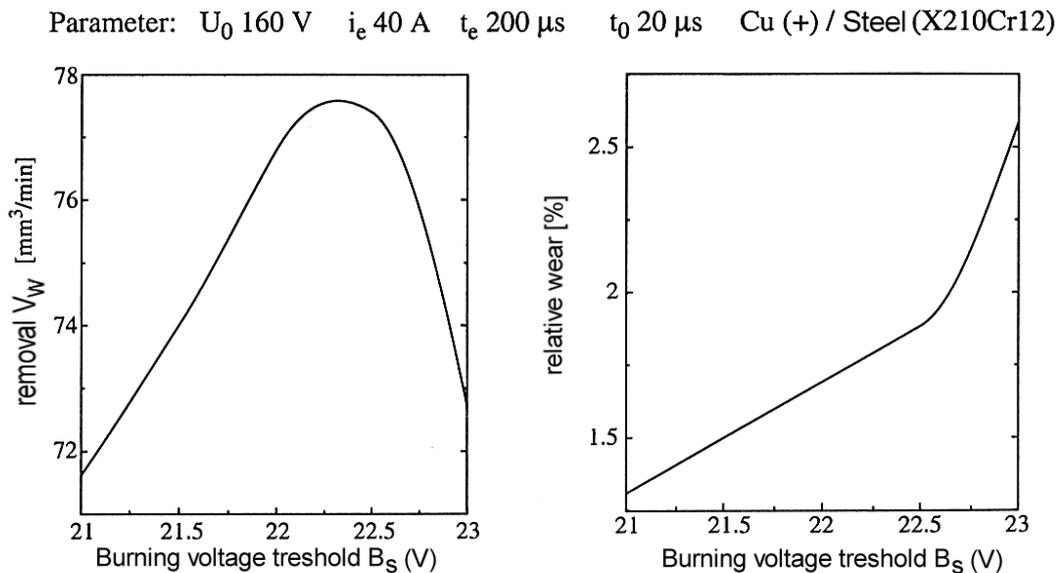


Figure 4. Removal behaviour at variation of the burning voltage threshold B_S

Figure 5 shows as a result from several experiments the position of the burning voltage threshold for different material combinations of electrode and workpiece. Normally the increasing current leads to an enlargement of the gap width. Therefore, as a rule, the optimal burning voltage threshold also increases with higher adjusted amperage. An exception make graphite electrodes in combination with steel workpieces at which the burning voltage threshold (24 V) is nearly independent from the amperage in combination with steel workpieces. The reason here is the specific contraction of the discharge channel, which leads to an improvement of the electrical conductivity of the gap if increasing current. On the other hand this behaviour will not be observed in case of erosion of TiAl6V4 with graphite electrodes.

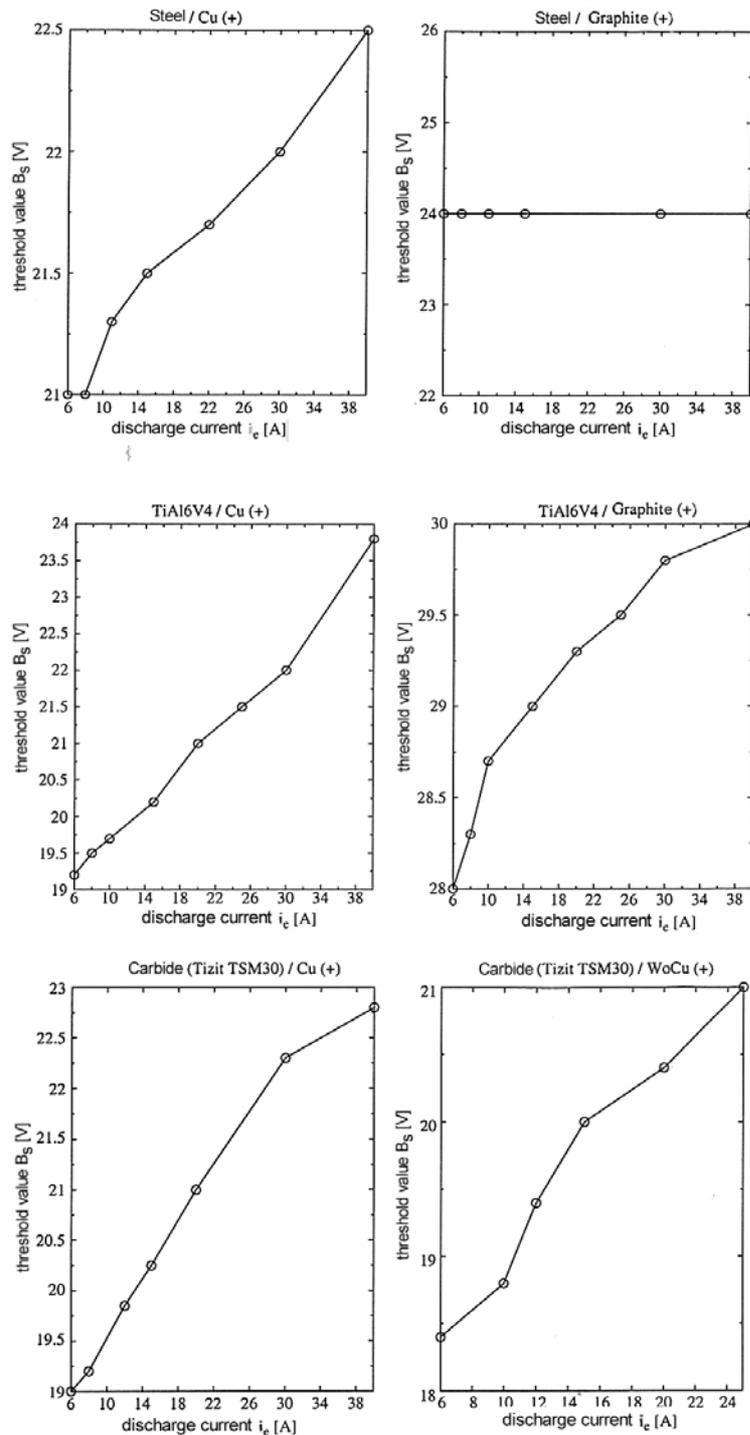


Figure 5. Burning voltage thresholds of different electrode/workpiece material combinations

The burning voltage threshold also can be used for the investigation of optimal technological parameter. This will be demonstrated in a second paper.

The efficiency of the arc detection by use of the burning voltage threshold in comparison to two other detection methods is demonstrated in table 1.

i_e	t_e	Process-status	Arcs detected by ...		
			Burning voltage threshold (B_s) Number of arcs	$t_d < 1\mu s$ Number of arcs	undershooting of ignition voltage threshold Number of arcs
6A	10 μs	stable	2476-3991	2-40	3-16
12A	30 μs		1749-3721	320-1779	61-191
20A	40 μs		748-4697	3-979	14-247
6A	50 μs	at the limit of stability	10424-13890	0-3	2-34
12A	100 μs		8350-11954	160-595	790-1004
20A	100 μs		9409-10032	176-473	832-1470
20A	100 μs	degenerated	12040-13382	0-376	8006-12733

Table 1. Arcs recorded by different detection methods (32 000 pulses)

The much greater number of arcs recognized by the threshold technique results from fact, that in this case the detection will be spread over the total time of discharging. In addition, this method enables an advantageously detection of the stability limits of the process at different parameter adjustments.

4. COMPARISON OF DIFFERENT GAP WIDTH CONTROLLER CONCEPTIONS

Now one should assume that the much higher number of detected arcs, which often effects a pulse cut-off already during the burning phase, leads to a reduction of the removal rate. Because the developed, intensively computer based process control system enables the implementation of different control strategies, three different conceptions were investigated for comparison purposes:

1. Gap width controller based on ignition delay time (t_d)
2. Gap width controller based on the relative frequency of open and short circuits (OC/SC)
3. Fuzzy gap width controller, based on the OC/SC-technique

The relative frequencies of OC/SC (time base 1 ms) can easily be obtained by using the thresholds mentioned in figure 1. Figure 6 demonstrates the architecture of the fuzzy controller.

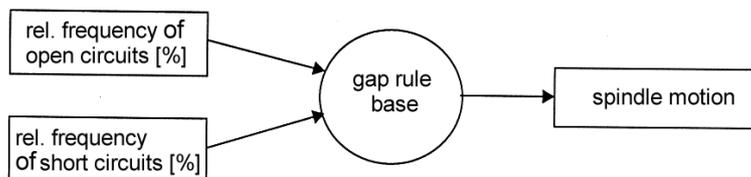


Figure 6. General fuzzy architecture of the OC/SC based gap width controller

Figure 7 shows the results in case of roughing and smoothing machining (special parameter settings see (10) or “www.erosion.de”). In every case identical adjustments (i_e , U_o , t_e , t_o) and isoenergetic pulses were used. Every controller settings were optimised before starting the experiments.

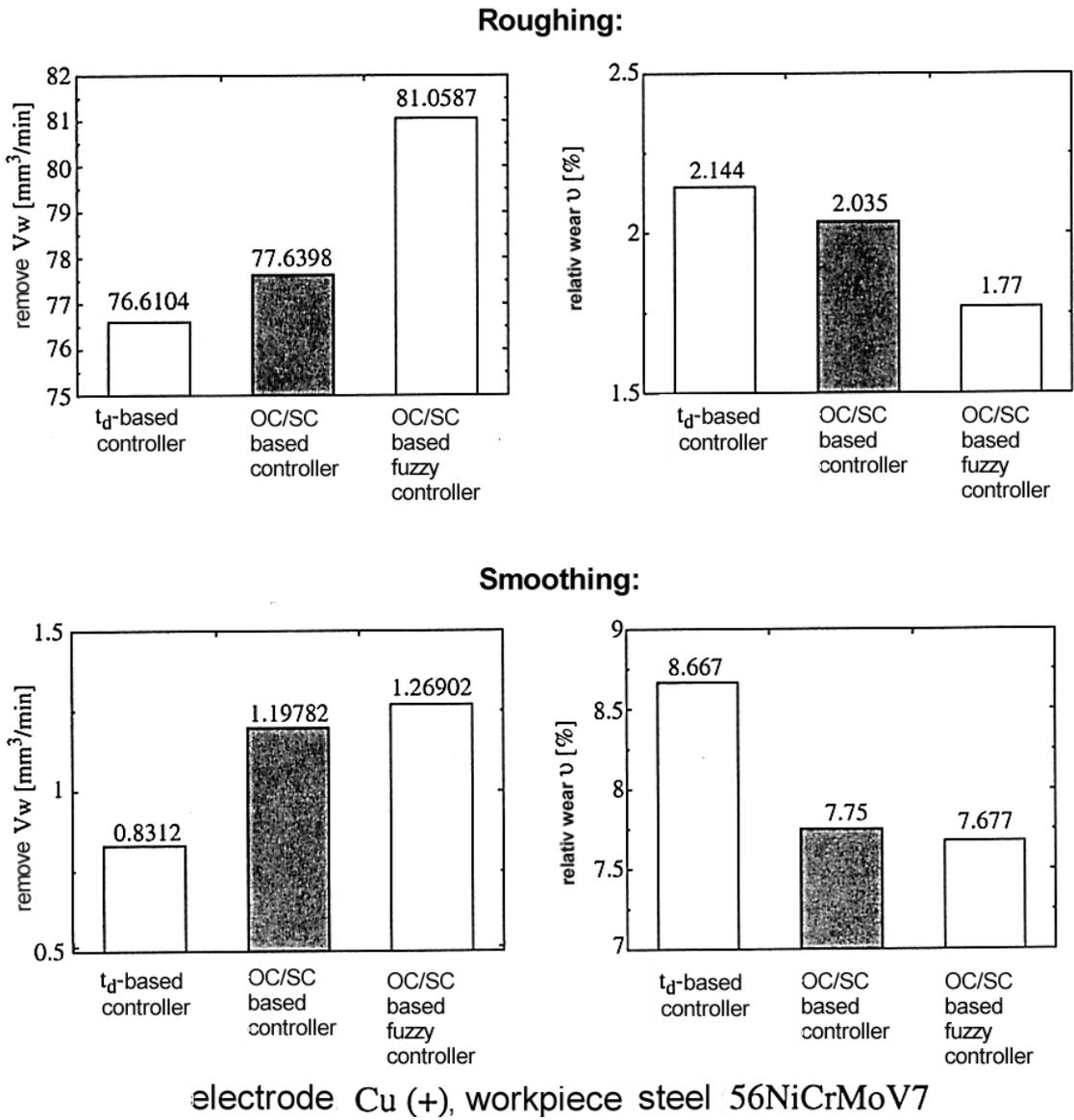


Figure 7. Comparison of the achieved removal and wear rate using different types of controller (shape of electrode see Tab. 2 at the end of this paper)

All results demonstrate the advantage of the OC/SC-based controller especially if integrating fuzzy architecture. Also remarkable is the lower wear rate, especially at smoothing operations. This involves that sharp outlines of the electrode will not be removed in such a way as it is the case using t_d -based controller. The reasons of the better removal results in comparison to a t_d -based controller are, that the arc detection based on the burning voltage threshold does not influence the gap width control movement of the electrode.

5. EROSION WITH 3D- AND PLANETAR MOTION WITH NEURO-FUZZY CONTROLLER.

Concluding a neural network will be integrated into the gap width control system, which enables an adaptive adjustment of the controller parameter to altering erosion conditions. This e. g. is advantageous for an unflushed sinking process because here the erosion conditions intensively deteriorate with growing electrode sinking depth. Figure 8 shows the architecture of the neural network and figure 9 its integration into the control system (12). The developed complex 4d-based CNC control system already was demonstrated at the last ISEM (11) and at (12). So it must not be explained once more. From the lot of results (10) only one will demonstrated (Tab. 2), concerning the 3d-starwise expansion of a hole (additional results see (10)). One may recognize from the length of erosion time, that in this case the integration of the neural network has a favourable effect only at smoothing conditions. This changes if vertical sinking parts dominate an erosion process.

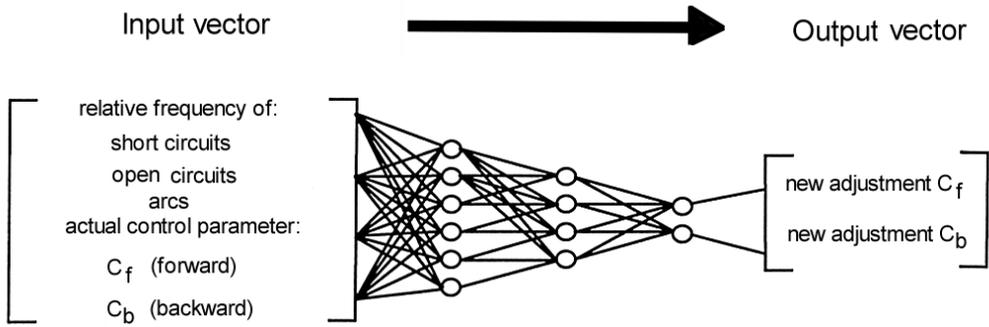


Figure 8. Schematic depiction of the neural network for controller adaption

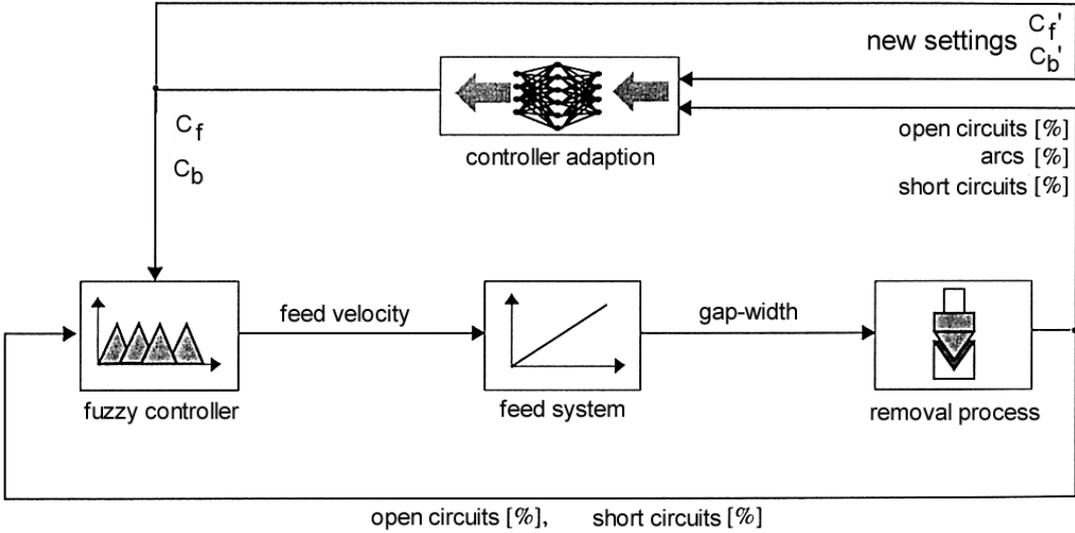


Figure 9. Gap width control and controller adaption

<p>motion at starwise expansion</p>	<p>Electrode</p>	<p>Roughing</p> <p>i_e: 40 A U_0: 160 V t_e: 200 μs t_0: 20 μs VPL: 500 μs B_s: 22,5 V N_{VPL}: 100 $N_{sp\ddot{u}l}$: 200 immersion: 9,65 mm</p>	<p>Smoothing</p> <p>i_e: 6 A U_0: 200 V t_e: 10 μs t_0: 30 μs VPL: 500 μs B_s: 21 V N_{VPL}: 10 $N_{sp\ddot{u}l}$: 20 immersion: 10 mm</p>
	<p>test conditions:</p> <p>Electrode: E-Cu (+) Workpiece: 56NiCrMoV7 Number of Electrodes: 2</p>	<p>Experimental Parameter:</p> <p>Expansion: 350 μm Steps: 3</p>	
controller	t_d -based	fuzzy	neuro fuzzy
roughing	32 minutes	30,5 minutes	30 minutes
smoothing	218 minutes	143 minutes	122 minutes

Table 2. Results of a 3d starwise expansion process

REFERENCES

1. **Snoeys, R.** and **Cornelissen, H.** (1975) Correlation Between Electro-Discharge Machining Data and Machining Setting. *Annals of the CIRP* 24 (1).
2. **Slomka, M.** (1989) Funkenerosives Senken- adaptive Vorschubregelung und Planetärbewegung. Dissertation, RWTH Aachen.
3. **Dehmer, J. M.** (1992) Prozeßführung beim funkenerosiven Senken durch adaptive Spaltweitenregelung und Steuerung der Erosionsimpulse. Dissertation, RWTH Aachen.
4. **Odensass, P. K.** (1995) Ein Verfahren zur Prozeßsteuerung und digitalen adaptiven Vorschubregelung funkenerosiver Senkanlagen. Dissertation, Universität der Bundeswehr Hamburg.
5. **Saiti, N., Kobayashi, K.** and **Olizumi, T.** (1982) Verfahren und Vorrichtung zur Elektroerosionsbearbeitung. Deutsches Patent DE 2362251.
6. **Timm, M.** (1996) Elektronische Stromquellen für das funkenerosioive Schneiden von elektrisch leitfähigen Werkstoffen. Dissertation, O. v. Guericke-Universität Magdeburg.
7. **Raabe, R. P.** (1999) Prozeßoptimierung für das funkenerosive Senken mit Neuro-Fuzzy-Control. Dissertation, RWTH Aachen.

8. **Dauw, D. F.** (1985) Online Identification and Optimization of Electro Discharge Machining. Dissertation, Katholische Universität Leuven.
9. **Witzak, M. P.** (1997) Verbesserung der Prozeßführungssysteme für funkenerosive Senkanlagen unter Einbeziehung von Fuzzy-Technologien. Dissertation, Universität der Bundeswehr, Hamburg.
10. **Ginzel, J.** (2002) Funkenerosives Senken mit Neuro-Fuzzy Prozeßführung und Fehlentladungsbehandlung unter Berücksichtigung der Bahn- und Planetärerrosion. Dissertation, Universität der Bundeswehr Hamburg. See also: www.erosion.de
11. **Behrens, A., Ginzel, J.** (2001) An open numerical control architecture for electro-discharge machining. Proc. 13th International Symposium for Electro Machining (ISEMXIII), Bilbao, S. 161 – 170.
12. **Behrens, A., Ginzel, J.** (2003) Neuro-Fuzzy Process Control System for Sinking EDM. Transactions North America Manufacturing Research Institution of SME, Vol. XXXI, S. 605-611.