Technology Development for EDM using Statistical Analysis of Arcing Information*

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SYNOPSIS

For the practical use of sinking EDM several technological parameters have to be adjusted in order to ensure secure and efficient working conditions. These are parameters determining the electrical impulse characteristics, parameters influencing the gap-width controller and parameters affecting the flushing mechanism. The final accuracy and surface quality is defined by these technological parameters. To obtain usable parameter-combinations, fitting to the intended EDM-application, extensive technological experiments must be carried out. Usually the producer of the ED-machine has done these experiments in advance for the most common applications. These technological data is normally offered to the user in form of a database. own experiments must be performed, if the users application doesn't fit to these predefined technological data sets. This paper proposes a simplified strategy for the implementation of these technological experiments.

1 CONVENTIONAL IMPULSE PARAMETER IDENTIFICATION

From the variety of parameters that have to be adjusted for efficient ED-machining, the impulse parameters are the most important (discharge current i_e, discharge duration t_e, ignition voltage U_0, pause time t_0). For instance the parameters of the gap-width controller or the flushing mechanism can be adjusted by an automatic adaptation (1). For impulse parameters the possibilities of automatic adaptation are limited, because of their influence on the discharge energy. They determine directly the surface quality and accuracy. In (2) the discharge energy (w_e) is defined as follows:

$$w_e = \int_{t=0}^{t_e} u_e(t) i_e(t) dt \approx \bar{u}_e i_e t_e \qquad \text{(Equ. 1)}$$

w_e: discharge energy
i_e : discharge current
t_e : discharge duration
u_e: burning voltage
$\bar{u}_e$: mean burning voltage

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From equation 1 it can be seen, that discharge current (i_e) and discharge duration (t_e) have the biggest influence on the discharge energy w_e (since $\bar{u}_e$ is depending mostly on the material combination and cannot be affected directly). Therefore the usual procedure for the identification of impulse parameters is to find a combination of i_e/t_e at first and than select the other missing parameters on the basis of this combination. To identify best combinations of i_e/t_e several removal experiments must be carried out. At first i_e is fixed and experiments with variable t_e are carried out. In order to find out the removal rate, each time a new workpiece- and tool-electrode is needed. The t_e setting showing the highest removal rate will be regarded as the best t_e. Figure 1 shows the removal rate for different t_e settings using a discharge current (i_e) fixed to 25A.

Machining Parameters: U_0 200V, i_e 25A, t_e variable, t_0 40µs, Cu (+) / TiAl6V4

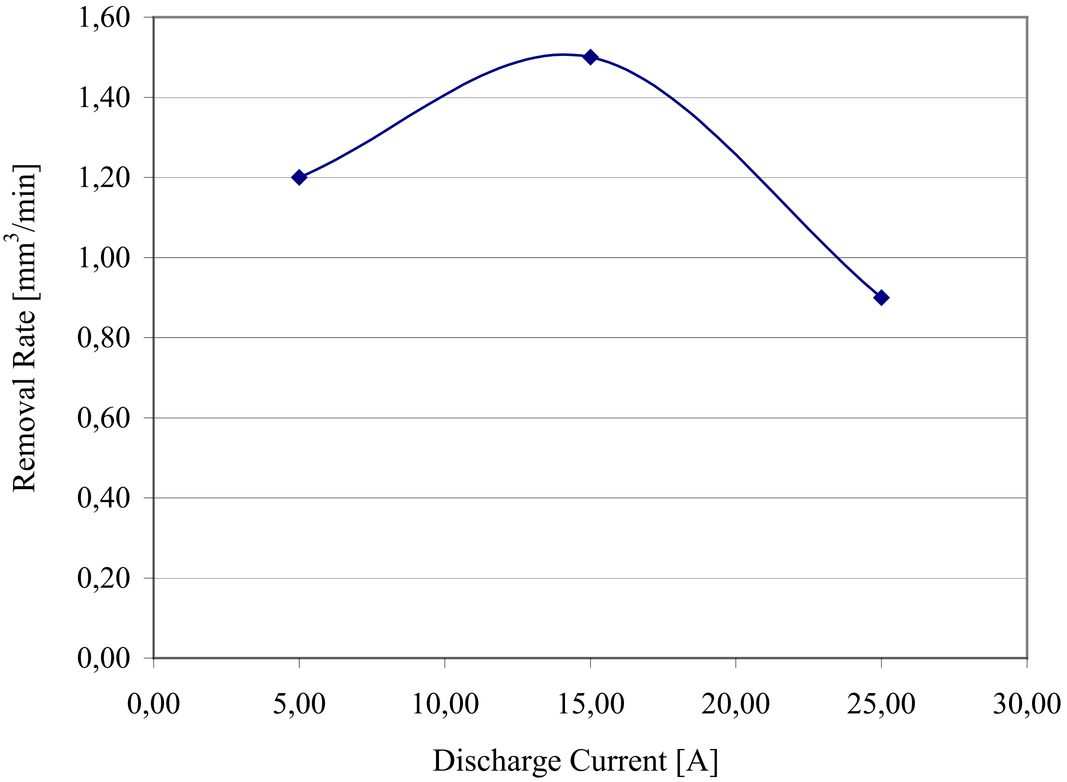


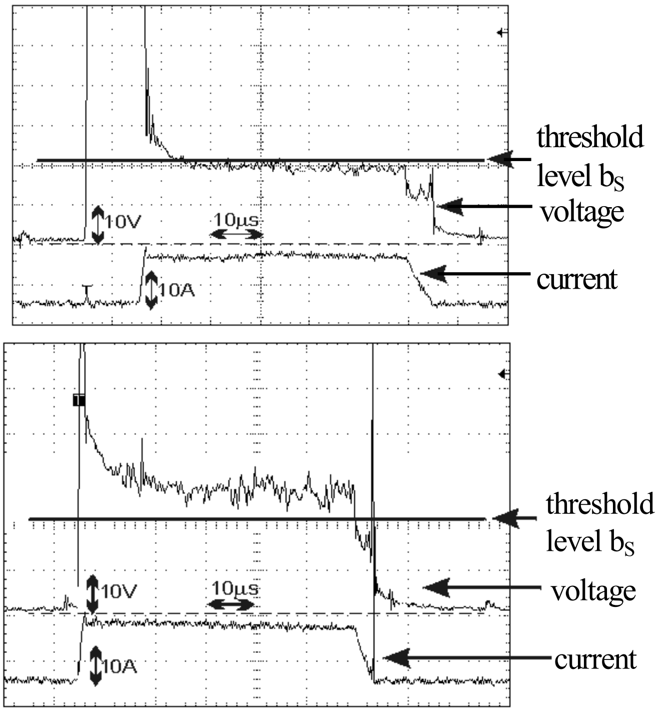
Figure 1. Removal rates for different discharge durations for TiAl6V4

From figure 1 it can be seen that concerning removal rate the combination i_e = 25A / t_e =15µs is the best, because removal rate shows a maximum at this value. For other discharge current values these experiments must be repeated. For a reliable measurement of removal rate each experiment needs some time (75 minutes for each experiment in figure 1). This means a big effort of time. It should be noticed, that the results of these experiments are valid only for the actual material combination (Cu(+) / TiAl6V4 in figure 1).

2 THE ARCING PHENOMENON

For the introduced impulse parameter identification the arc detection method by using the burning voltage threshold (b_s) is fundamental. This arc detection method implies that every normal discharge shows a specific burning voltage staying above a fix voltage level. This burning voltage level is determined by the material combination and the discharge current i_e. Therefore a threshold level b_s can be used to distinguish between a normal discharge (staying above the threshold level b_s) and an abnormal discharge (falling below the threshold level b_s). Figure 2 shows a normal and an abnormal discharge.

Machining Parameters: U_0 160V, i_e 15A, t_e 50µs, t_0 40µs, Cu (+) / Steel (56NiCrMoV7)



abnormal discharge:
burning voltage falls below thethreshold level b_s

normal discharge:
burning voltage stays above the threshold level b_s until the end of the burning time

Figure 2. Normal and Abnormal Discharge

The abnormal discharge raises the danger of arcing and must be avoided, in order to prevent surface destruction on workpiece- or tool-electrode. In contrast to other arc detection methods (e.g. ignition delay-time (3), ignition-voltage-level (4)) arc detection by burning voltage threshold monitors each ignition during the complete burning phase (5). Therefore even those abnormal ignitions will be detected, who start as a normal ignition and change into abnormal during burning phase.

By changing the burning time (t_e) it turned out, that every discharge would change into abnormal if t_e is extended long enough. To prove this, t_e was extended for several ignitions. Additionally the time from the beginning of the burning phase until the transformation of the discharge into abnormal (t_{arc}) was recorded (for the definition of t_{arc} see figure 3).

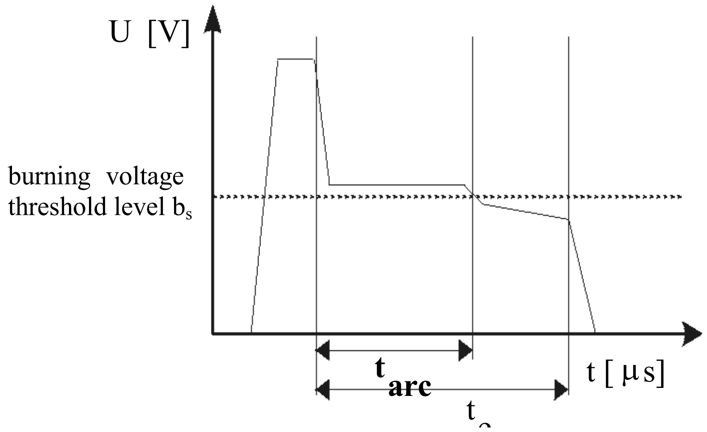


Figure 3. Definition of t_{arc}

During a finishing operation 15.190 discharges were recorded. From those recorded discharges 2.886 changed into abnormal by falling with their burning voltage under the threshold level b_s. For those abnormal discharges the histogram of the t_{arc}-values can be seen in figure 4.

Machining Parameters: U_0 200V, i_e 6A, t_e 30µs, t_0 10µs, Cu (+) / Steel (56NiCrMoV7)
Total number of recorded discharges: 15.190
Total number of abnormal discharges: 2.886

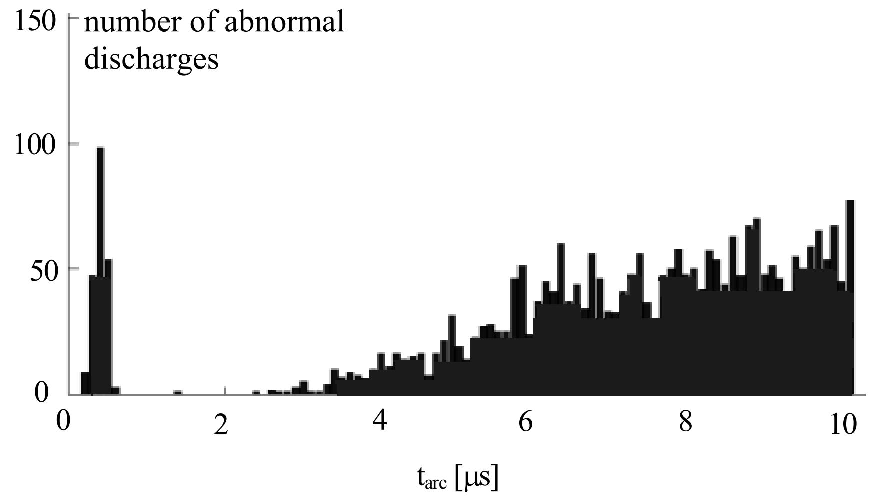


Figure 4. Histogram of t_{arc} recorded during stable process condition

The overall process situation of the finishing operation in Figure 4 can be described as "stable" because of the low portion of abnormal discharges (2.886 from 15.190 discharges). While running this finishing operation, the burning time t_e was abruptly extended to t_e = 50µs (from t_e = 10µs). Exactly with the abrupt extension of t_e the recording of another 15.310 discharges started. After recording those pulses t_e was set back to its former value (t_e = 10µs), in order to avoid surface destruction on the electrodes. From the discharges recorded with extended t_e a number of 13.890 changed into abnormal by falling under the threshold level b_s. For those abnormal discharges the histogram of the t_{arc}-values can be seen in figure 5.

Machining Parameters: U_0 200V, i_e 6A, t_e 50µs, t_0 10µs, Cu (+) / Steel (56NiCrMoV7)
Total number of recorded discharges: 15.310
Total number of abnormal discharges: 13.890

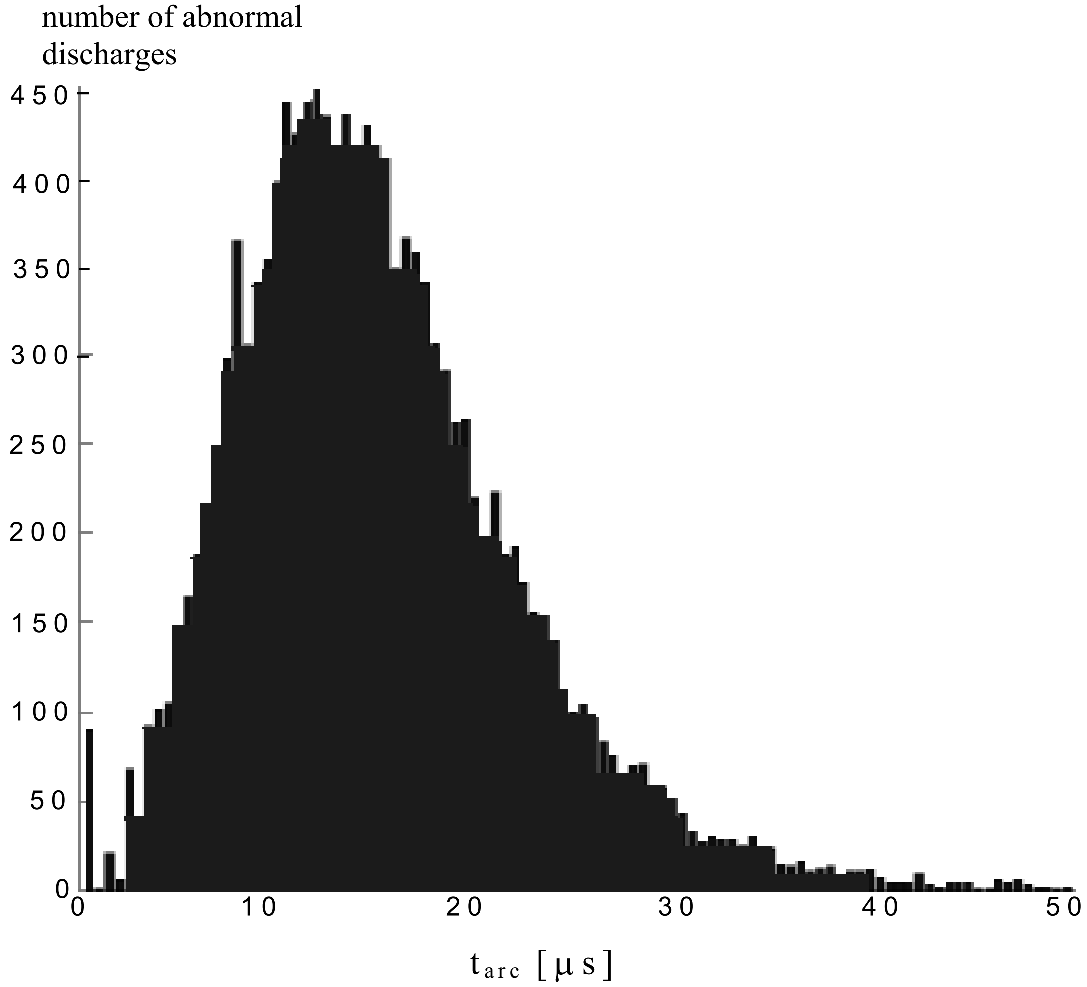


Figure 5. Histogram of t_{arc} recorded during extended burning time

Comparing figure 4 with figure 5 it can be seen, that the number of abnormal discharges is drastically increased due to the extended burning time t_e. During extended burning time nearly every discharge changed into abnormal (more than 90% of the recorded 15.310 discharges). This confirms the assumption, that every discharge will change into abnormal if t_e is extended long enough.

By analyzing the t_{arc} values of figure 5 with statistical methods, it is possible to identify a probability distribution. Using the Kolmogoroff-Smirnov-Test (6) with a significance level of 0,01 it could be confirmed that the t_{arc}-values of figure 5 can be associated with the Weibull distribution (7). The definition of the Weibull distribution is given in equation 2 and equation 3.

$$f(t) = \alpha\beta t^{\beta-1} e^{-\alpha t^{\beta}}$$ for α>0, β>0 (Equ. 2)

$$F(t) = 1 - e^{(-\alpha t^{\beta})}$$ for α>0, β>0 (Equ. 3)

f(t) : Probability Density Function *F(t)*: Cumulative Distribution Function

To obtain the two parameters in equation 2 and equation 3 the Maximum-Likelihood method (8) was used. With a confidence Interval of 95% the two parameters α and β could be identified to:

α: 0,00108593126262 (confidence interval: 0,00098 – 0,00119)
β: 2,46584810774382 (confidence interval: 2,43360 – 2,49810)

An important field of application for the Weibull distribution is the probability analysis of an outage of a technical system (9). The Weibull distribution is often used in cases were the technical system shows signs of degeneration (the probability of an outage increases with ongoing operating time). If the vocabulary of outage analysis is transferred to the analysis of abnormal discharges the following associations can be made:

The system outage	*is equivalent to*	the changing of a normal discharge into abnormal
The operating time of the system	*is equivalent to*	the discharge duration t_e

The failure rate (or outage probability) is important for system outage analysis equation 4 shows the definition:

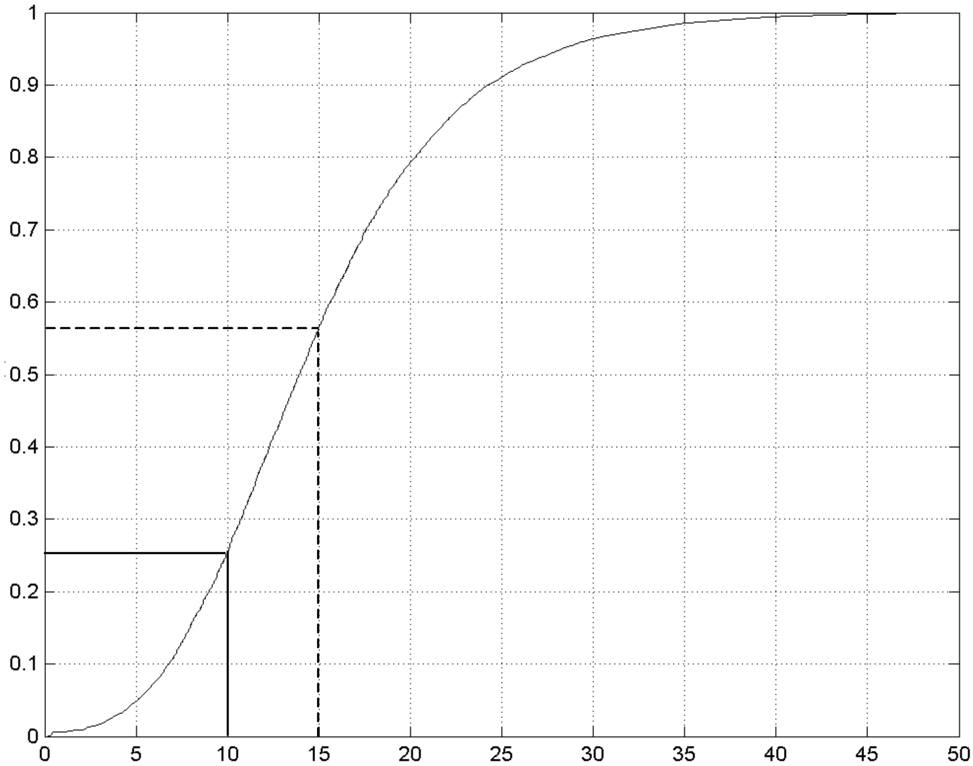
$$A(t) = \frac{f(t)}{1 - F(t)} \qquad \text{(Equ. 4)}$$

f(t) : Probability Density Function *F(t)*: Cumulative Distribution Function

The failure rate is equivalent to the changing rate for normal discharges into abnormal discharges (or mutation rate). The mutation rate raises nearly linear with the ongoing of the burning time. If t_e is selected too long, too many abnormal discharges will be the result. In order to find out, how t_e should be selected, the empirical cumulative distribution function for the t_{arc}-values in Figure 5 is important.

The empirical cumulative distribution function in Figure 6 shows, that after 15µs already 57% of the discharges changed into abnormal. This high portion of abnormal discharges will lead to instable process behavior. After 10µs burning time only 25% of the discharges changed into abnormal. Own experiments prove that an abnormal discharge portion of 25% can be tolerated. Therefore it can be concluded, that for the process parameters in Figure 5 (Copper/Steel (-) ; i_e = 6A; U_0=200V; t_0=30µs) t_e can be set to 10µs maximum. The number of abnormal discharges can be reduced slightly, if t_e is set to a smaller value than 10µs. But this will not considerable improve the process stability, because setting t_e to 10µs will already produce a stable process situation (as demonstrated in Figure 4). Setting t_e to a value smaller than 10µs will reduce the removal rate, because discharge energy is reduced (see equation 1).

Portion of abnormal discharges showing t_{arc}-values less or equal



t_{arc} [μs]

Figure 6. Empirical cumulative distribution function for the t_{arc}-values from Figure 5

3 IMPULSE PARAMETER IDENTIFICATION USING t_{arc} ANALYSIS

The effort for Impulse parameter identification can be reduced, if the knowledge of t_{arc} analysis is included. To find out a fitting t_e for a given i_e there is no need to perform several removal experiments, each one with a different combination of i_e/t_e (as done in figure 1). The combination of i_e/t_e can be found within seconds by simply looking at the t_{arc}-histogram and the empirical cumulative distribution function of abnormal discharges recorded during extended t_e. The procedure for this identification process is given in the following:

1. Start the ED-operation for a given i_e with a short t_e in order to ensure a stable process behavior and a low arc portion. The pause-time t_0 should be selected long enough to avoid arcing due to insufficient deionization. If t_0 is selected too long there will be no negative influence on the identification process.
2. During a stable process situation, t_e must be extended abruptly to a much longer value in order to obtain a lot of abnormal discharges. This extended t_e should be kept only for some impulses (approx. 10.000). Destruction on the electrode surfaces can be avoided, by setting back t_e to its original short value after these discharges.

3. The t_{arc} time should be captured and recorded for the abnormal discharges, while the process runs with extended t_e.
4. The best t_e setting can be extracted from the histogram and the empirical cumulative distribution function of the t_{arc} values. For a stable process behavior t_e should be set to value with an arc portion of approximately 25%.

4 APPLICATION OF THE IDENTIFICATION PROCESS FOR TiAl6V4

Exemplary the procedure for obtaining the i_e/t_e combination was carried out for the discharge current i_e=25A and the same material combination as in figure 1. At start the burning time t_e was set to 10µs. The burning time was extended abruptly to 80µs and 13.002 discharges were recorded. From these discharges a number of 13.000 changed into abnormal. The histogram of the recorded t_{arc} values and the empirical cumulative distribution function can be seen in Figure 7.

Machining Parameters: U_0 200V, i_e 25A, t_e 80µs, t_0 40µs, Cu (+) / TiAl6V4

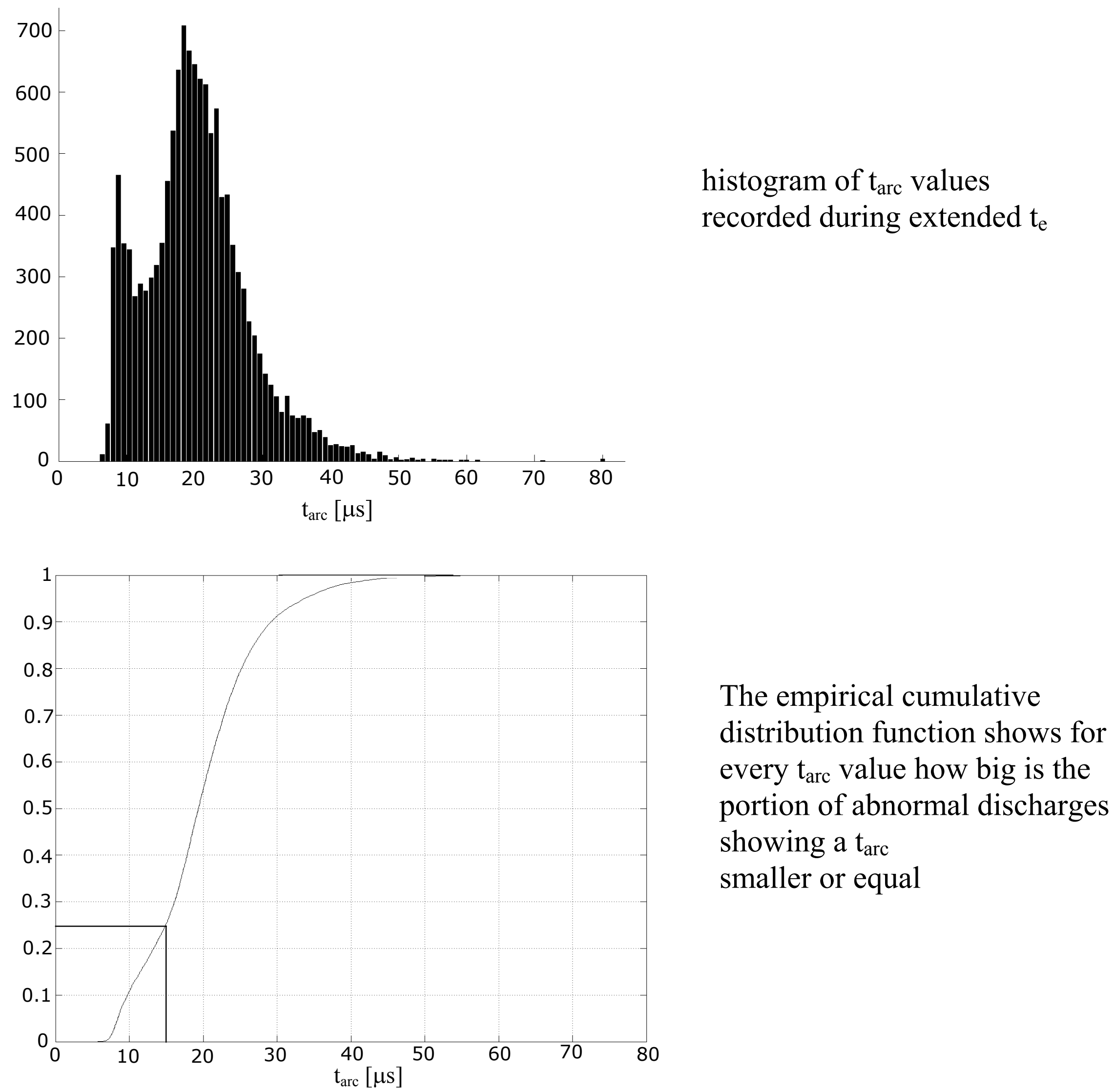


Figure 7. Histogram and empirical cumulative distribution function for TiAl6V4

From Figure 7 it can be seen that after 27µs of burning time 25% of the discharges changed into abnormal. This percentage of abnormal discharges can be tolerated. Therefore the combination i_e=25A/t_e=27µs provides stable process conditions. For other discharge currents the experiment was repeated. This way technological data for TiAl6V4 could be acquired very fast. All identified i_e/t_e combinations can be seen in figure 8.

Machining Parameters: U_0 200V, i_e variable, t_e variable, t_0 40µs, Cu (+) / TiAl6V4

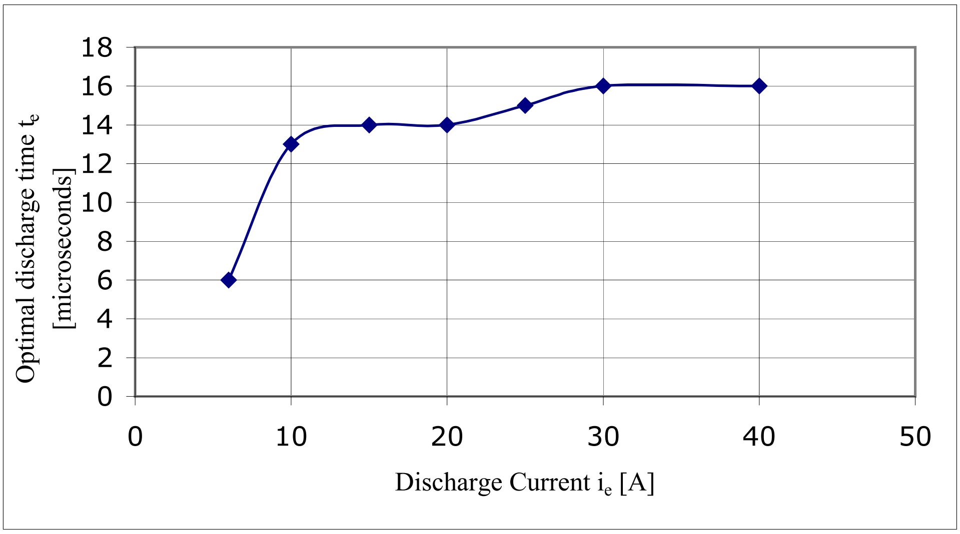


Figure 8. Identified combinations of I_e/t_e for TiAl6V4 using t_{arc} analysis

In the next step the ignition voltage U_0 must be adjusted. U_0 has main influence on the gap-size and therefore on the accuracy. A big ignition-voltage U_0 will cause a wide erosion-gap and good flushing conditions. This can produce a stable process behavior. The disadvantage of a wide erosion-gap is the reduced accuracy. For this reason U_0 should be reduced as small as possible. The last impulse parameter to be adjusted is the pause-time t_0. The pause time should be reduced as much as possible to avoid time-waste. If t_0 is selected too small, arcing will be the result because of insufficient de-ionization.

5 CONCLUSION

The use of appropriate impulse parameters is important for process stability and removal rate in sinking EDM. The impulse parameters determine directly the discharge energy. Therefore they have big influence on the surface and the accuracy of the workpiece. The identification of impulse parameters is difficult and time consuming. A considerable improvement in impulse parameter identification can be achieved, if the t_{arc}-time is used for this purpose. By analyzing the t_{arc}-values recorded with extended t_e with statistical methods it is possible to determine the best combination i_e/t_e directly. The statistic background of the identification procedure was illustrated using the Weibull distribution.

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