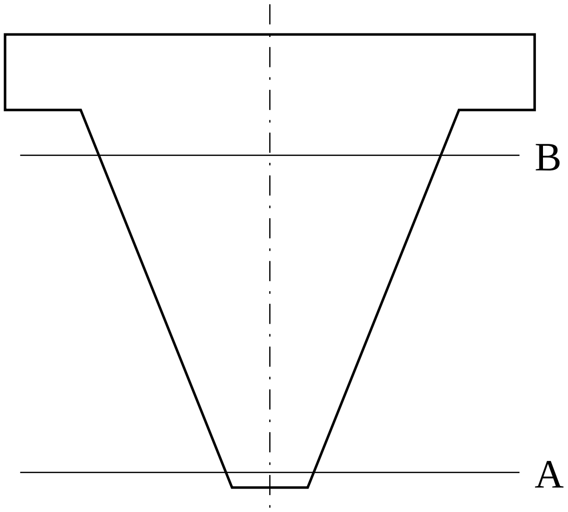
Monitoring of the Effective Size of the Electrode in EDM

$$E = \int_0^{t_e} U(t) \cdot I(t) \cdot dt$$



Setup parameters: $A = B$
Effective size of the electrode: $A << B$

Position	Problems
A	instability of the process high electrode wear
B	/

- monitoring (what?)
- evaluation, reasoning (how?)
- control actions (which?)

- Two experiments with the same setup parameters but different effective size of the electrode.
- Acquire the electric current signal in the gap.
- Isolate parts of the signal where discharges occur.
- Define the parameters on each discharge.
- Build a system for classification of the discharges to each experiment.

$$\Downarrow$$

If classification is successful the electric current in the gap is enough informative about effective size of the electrode.

Experiment

Machine: Ingersoll 80P

INPUT:

Workpiece material: hardened steel

Electrode material: copper

Dielectricum: Castrol SE-Fluid 180

Setup parameters: $\hat{i}_e = 26\ A$

$u_i = 110\ V$

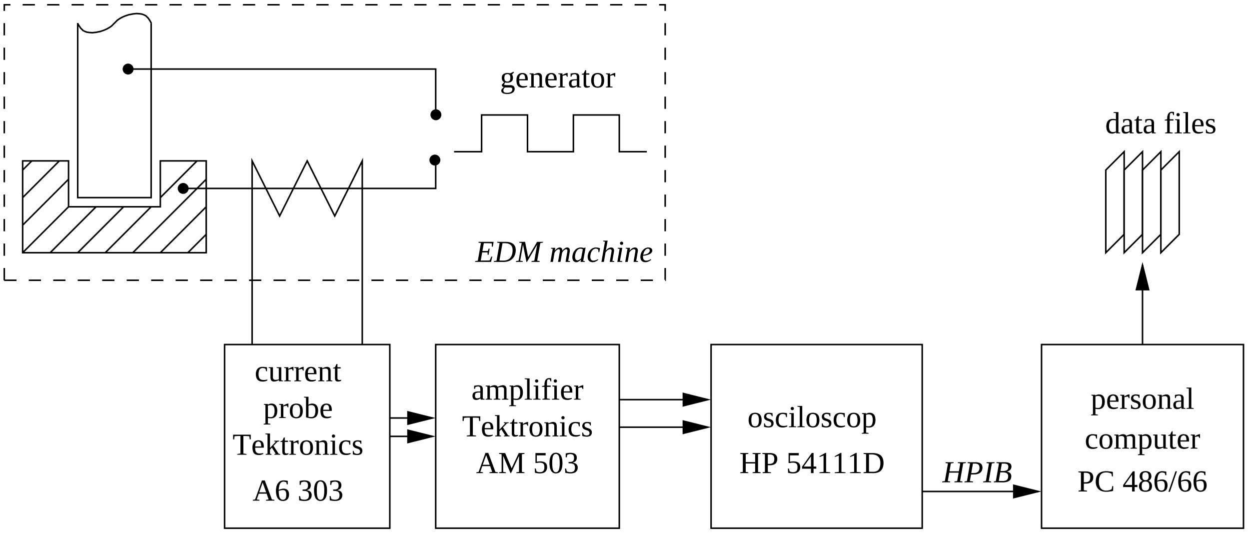
$t_i = 450\ \mu s$

Effective size of the electrode: $A_1 = 12.6\ mm^2$

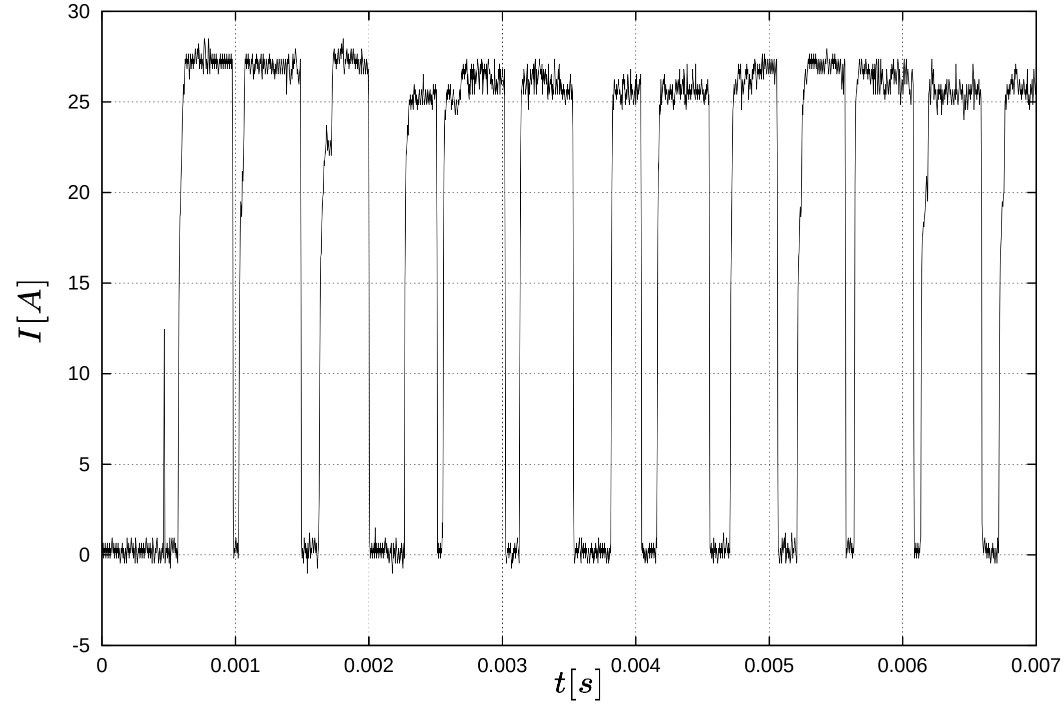
$A_2 = 314\ mm^2$

OUTPUT:

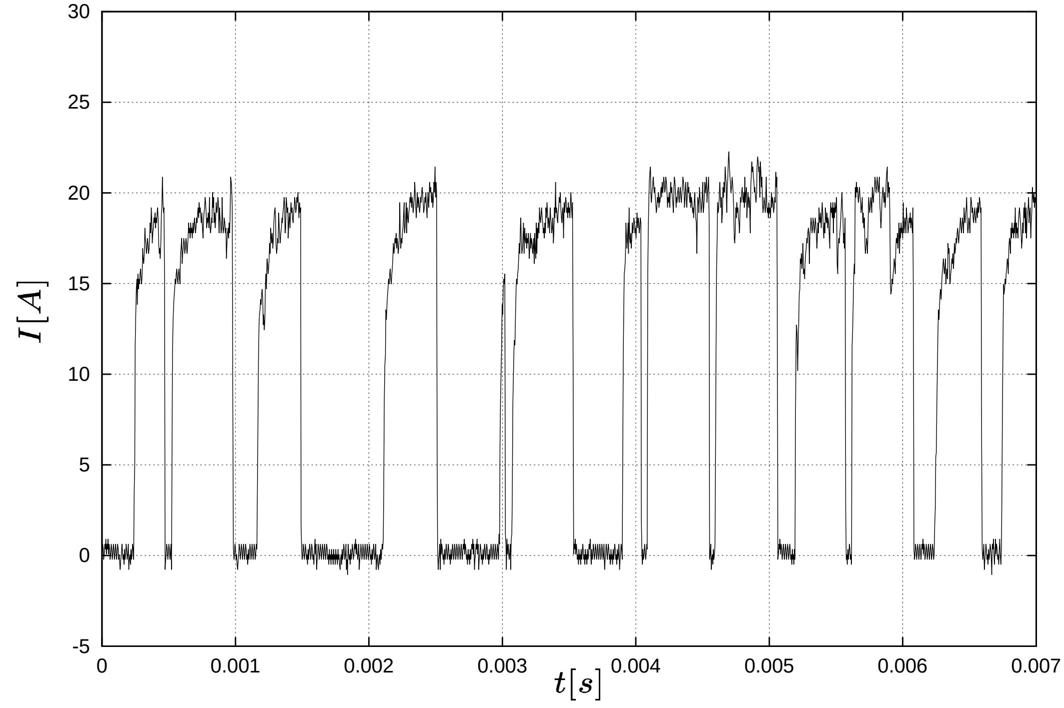
Electric current signal $I(t)$ in the gap



Electric current signal in the gap

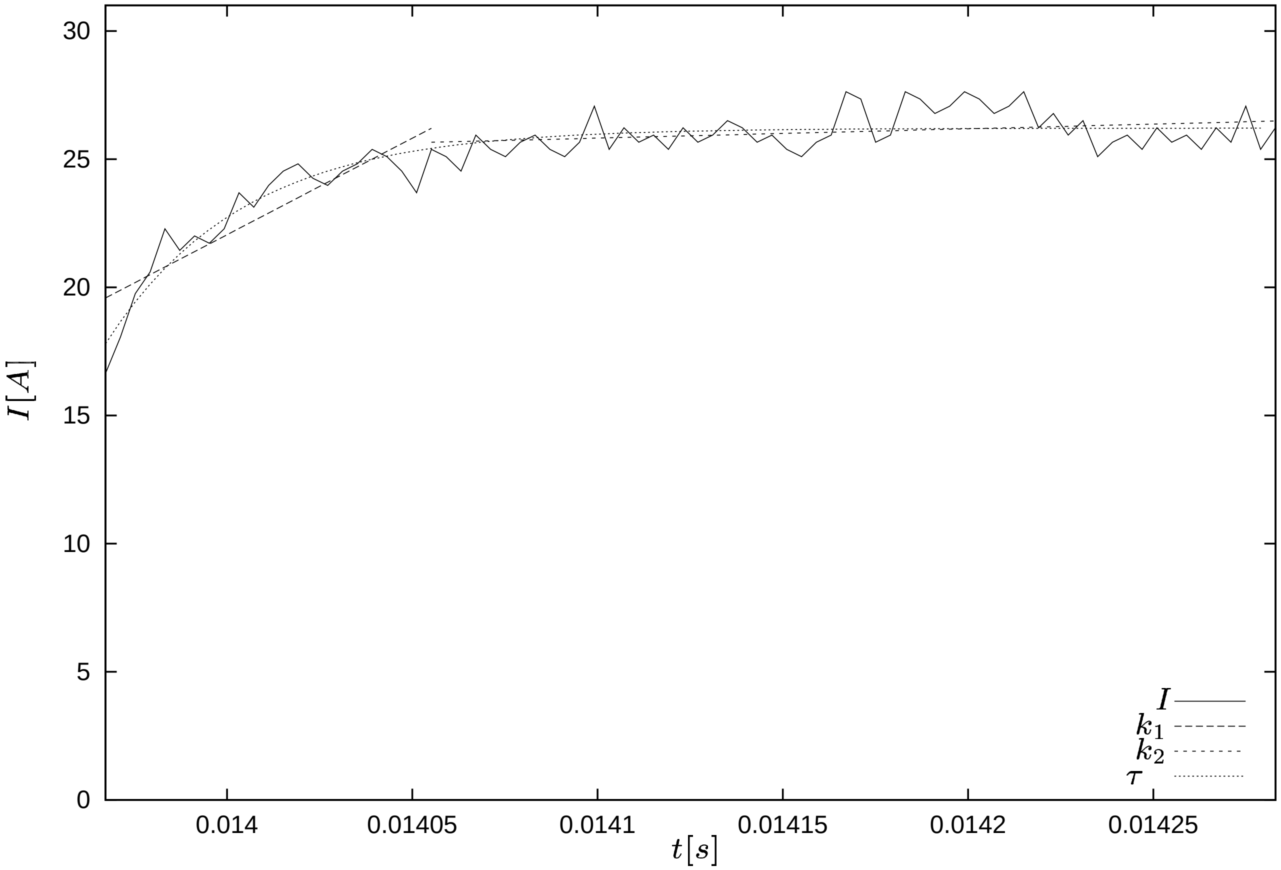


Electrode A_1: 320 discharges



Electrode A_2: 320 discharges

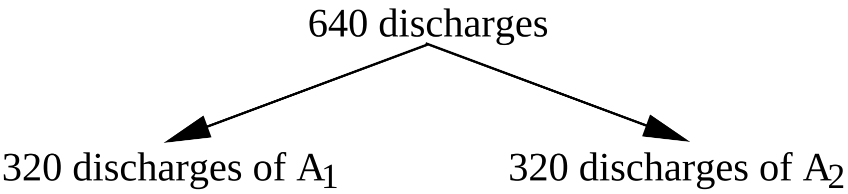
Discharge attributes on the electric current signal



$$
\begin{aligned}
\sigma(\bar{\mathbf{i}}_{\mathbf{e}}) &= \sqrt{\frac{\sum_{i=-15}^{15}(\bar{i}_{e,i} - \bar{\bar{i}}_e)}{30}}, \\
\hat{I} &= k_1 \cdot t + n_1. \\
\hat{I} &= k_2 \cdot t + n_2. \\
\hat{I} &= \tau_1 - e^{(-\tau_2 \cdot t)}
\end{aligned}
$$

Curve fitting criterion:

$$SSE = \sum_{i=1}^{N} (\hat{I}_i - I_i)^2$$



640 discharges

320 discharges of A_1 320 discharges of A_2

Each discharge is represented by five dimensional vector

$$\mathbf{x} = [\sigma(\bar{\mathbf{i}}_{\mathbf{e}}), k_1, k_2, \tau_1, \tau_2]$$

and for each discharge the effective size of the electrode is known.

$y \in \{0, 1\}$:

$y = 0$ ... electrode effective size $= A_1$

$y = 1$ ... electrode effective size $= A_2$

A non-parametric method which works also in the case of non-linearity was used - Conditional Average Estimator (CAE).

$$\left.\begin{array}{l}\text{160 discharges of } A_1\\ \text{160 discharges of } A_2\end{array}\right\}\text{ as examples } (\mathbf{x}, y):$$

The rest of the discharges were classified by CAE:

Conditional average estimator

The CAE is in the case of multiple-input single-output defined by the following equation:

$$\hat{y}(\mathbf{x}) = \frac{\sum_{k=1}^{K} y_k \, w(\mathbf{x}, \mathbf{x}_k, \lambda)}{\sum_{l=1}^{K} w(\mathbf{x}, \mathbf{x}_l, \lambda)},$$

where

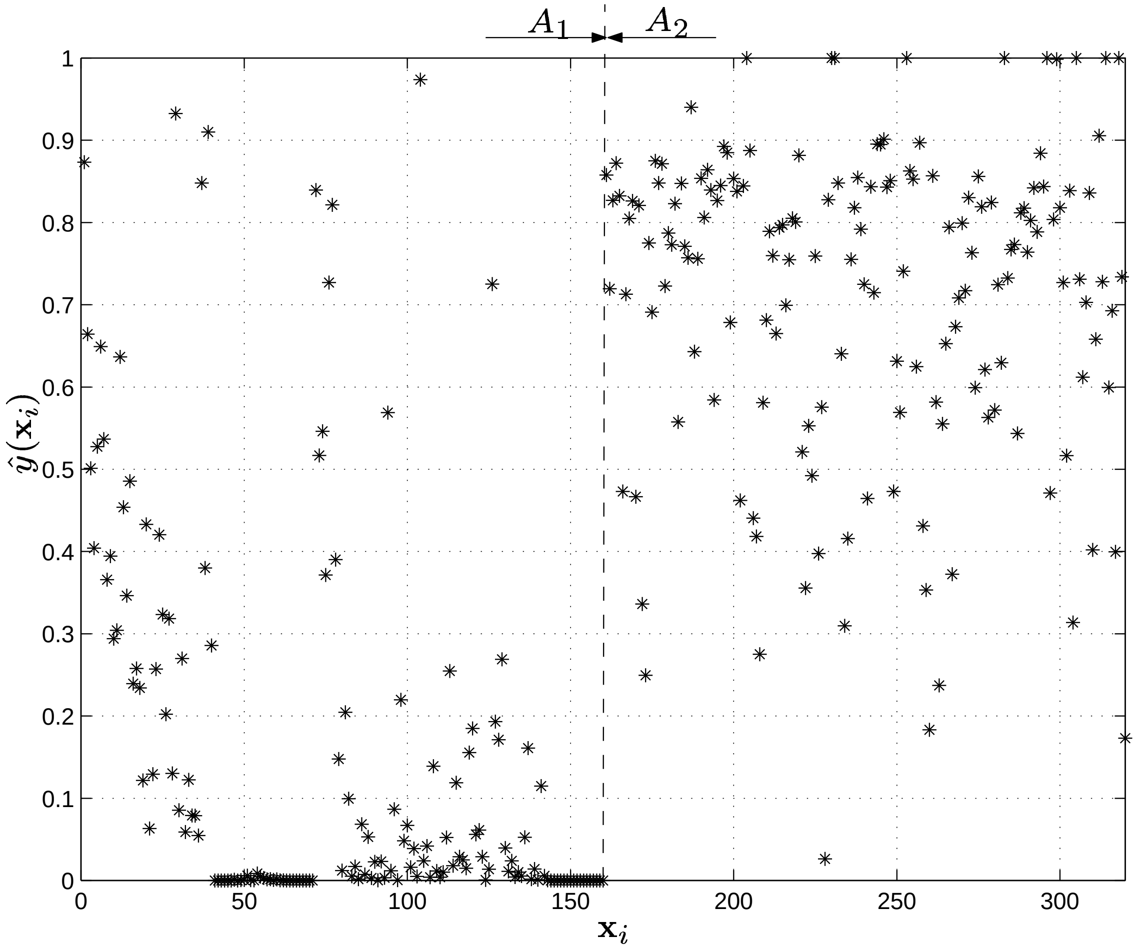
$$w(\mathbf{x}, \mathbf{x}_k, \lambda) = exp\left(- \frac{\sqrt{\sum_{i=1}^{N} (x_i - x_{ki})^2}}{2\lambda^2} \right).$$

The value of the smoothing parameter λ is established according to the smallest mean square error:

$$MSE = \frac{1}{N} \sum_{k=1}^{K} \left(\hat{y}_k - y_k\right)^2.$$

Results

Classification of discharges with smoothing parameter $\lambda = 0.46$. Achieved mean square error $MSE = 0.20$.



- There is high rate of similarity between discharges.
- The aim is to detect suitability of the discharge energy and not to classify single discharges.
- If $\hat{y}(\mathbf{x}_i) > 0.5$ determines appropriate discharge energy and $\hat{y}(\mathbf{x}_i) < 0.5$ determines too high discharge energy then only $10\ \%$ of discharges were wrongly classified.

Conclusions

- The electric current signal in the gap during the discharge could be enough informative about proper values of setup parameters according to the effective size of the eroding surface.
- Monitoring of the electric current can be done on-line. Thus the effective size of the electrode can be established during the machining.
- The achieved results are promising for future researches:
  - experiments with smaller differences in the effective size of the eroding surfaces and
  - experiments with graphite electrode and various workpiece materials.
- A system able to detect the effective size of the electrode and to control the setup parameters enables machining without feeding the effective size of the electrode into the machine controller before machining.