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ELECTRICAL DISCHARGES AT HAND GAP CONTROL WHEN APPLYING ED-MACHINING. EDM 60 Years

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1. IGNITION OF ELECTRICAL DISCHARGES

Sixty years passed since the LAZARENKO [1] proposal 1943 to invert the effect of metal removal from electric power switches from minimisation to maximisation for metal machining purposes. In the early years of development and application ot this proposal with relaxation type generators (charging condensers to store discharge energy), the pause between discharges was very long and ignition from ionisation effects in the gap through high field strength between the electrodes was assumed by closely all scientists [2–4]. The physicist even until today have difficulty however to clearly define differences between sparks and arcs. The application in workshops instead found quickly a good distinction. “Spark” machining is needed for manageable, precise and good quality work, while “Arcing” characterizes deteriorated machining, which results in discharge concentration, melting and overheating at surface spots.

Apart from spark ignition theories there exist also differences in respect to the metal removal procedure, resulting predominantly from thermal effects (Joule’s heat) but also from thermal shocks, field strength or mechanical stress.

When with the appearance of semiconductor switched static pulse generators at the early sixties duty cycles up to 99% became applied, a new discussion around probable ignition started. The heavily increased amount of metal removal further caused by the generation of gas and by the eroded particles a rather high conductivity inside the gap.

It became further apparent, that physical investigations with single discharges over a fixed gap distance in clean dielectric liquids [5–7] produce metal removal rates much higher, than what can be measured in common EDM application in servo-controlled operation.

2. THEORY ON PRACTICAL EDM

After 50 years of meanwhile important application of EDM as production technology, the description of the enrolment of the process in the small gap by different authors has not yet found a uniform interpretation. This paper therefore tries to create a new consensus base.

2.1. Phases of electrical discharges

The first picture (Fig. 1) separates three important phases in the electrical discharge procedure as practically used.

Preparation phase for ignition
Phase of discharge
Interval phase between discharges

2.1.1. Preparation phase for ignition

When the generator switches voltage on, the electric field reaches highest strength in the area, where electrode surfaces are closest and where particles in the gap assist. Ignition will not take place in former discharge channels (remaining gas bubble), as those show a much longer existence than on-time endurance. The author is convinced and a high speed film (available on DVD) has given prove, that thin particle bridges between the electrodes define the new discharge area [8, 9]. They become evaporated to form a high temperature plasma by this current flow. Many observations support this theory.

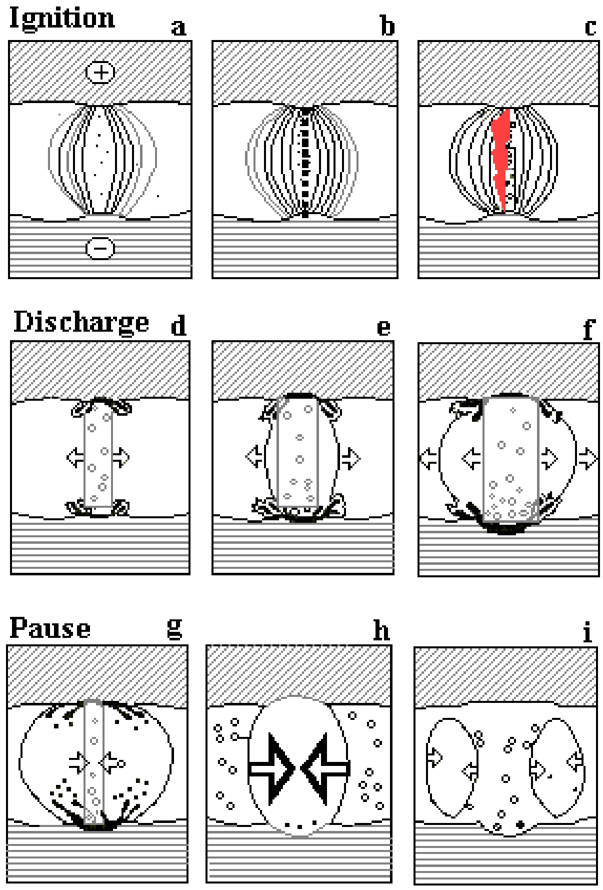

Fig. 1. Phases of electrical discharges

A minimum current (3A) is needed to start discharges, requested power for particle evaporation. Ignition delay (particle evaporation time) is needed in servo controlled EDM processes. EDM processes run with low field strength ignition. Gap widens immediately after fresh start caused by debris in gap [10]. Discharge off-times of only 5–10 µs are sufficient. The working area in EDM influences off-time need. Gap width results in dependence of removal rates, means from amount of debris in gap. Single discharge conditions [5–7] are not comparable with servo controlled EDM. Measurements of R. Crowe [5] prove influence of delay time.

Areas of high concentration of debris are especially around earlier discharges, because ejected material will be collected in the liquid while freely passing the gas channel. Discharge spots on surfaces show typical arrangement for their distance [8, 11] See explanations given in Fig. 2.

This spot arrangement of craters can also be used, to define the resulting surface roughness by calculation derived from the crater shape and distance. The measurements of R. Crowe (Fig. 3) indicate, that undelayed ignition of discharges (“on times”of nanoseconds) requests extremely high field strength. For longer on-time the larger gaps ignite easier because debris can arrange particle bridges to define the discharge channel by evaporation (“particles” may be gas balls, debris, impurities, humidity). In practical applications the gap width is much higher than in tests of R. Crowe.

2.1.2. Phase of discharge

The first plasma channel has to become developed in shortest time against the front of dielectric. The result is very high pressure inside the channel creating also a shock wave distribution within the liquid. The current passing the gap creates high temperatures causing material evaporation at both electrode spots. As the electron processes (smaller mass than anions) show quicker reaction, the anode material is worn predominantly. This effect causes a minimum wear to the tool electrodes and becomes of importance under finishing operations (short on-times).

Current density and temperature afterwards decrease quickly with the continuous growth of the plasma channel. The plasma channel diameter stabilises when an equilibrium is reached between energy supply from the generator and heat flow to electrodes as well as to further evaporation of liquid and into the dielectric. The liquid evaporation continues to enlarge now a gas bubble around the plasma channel.

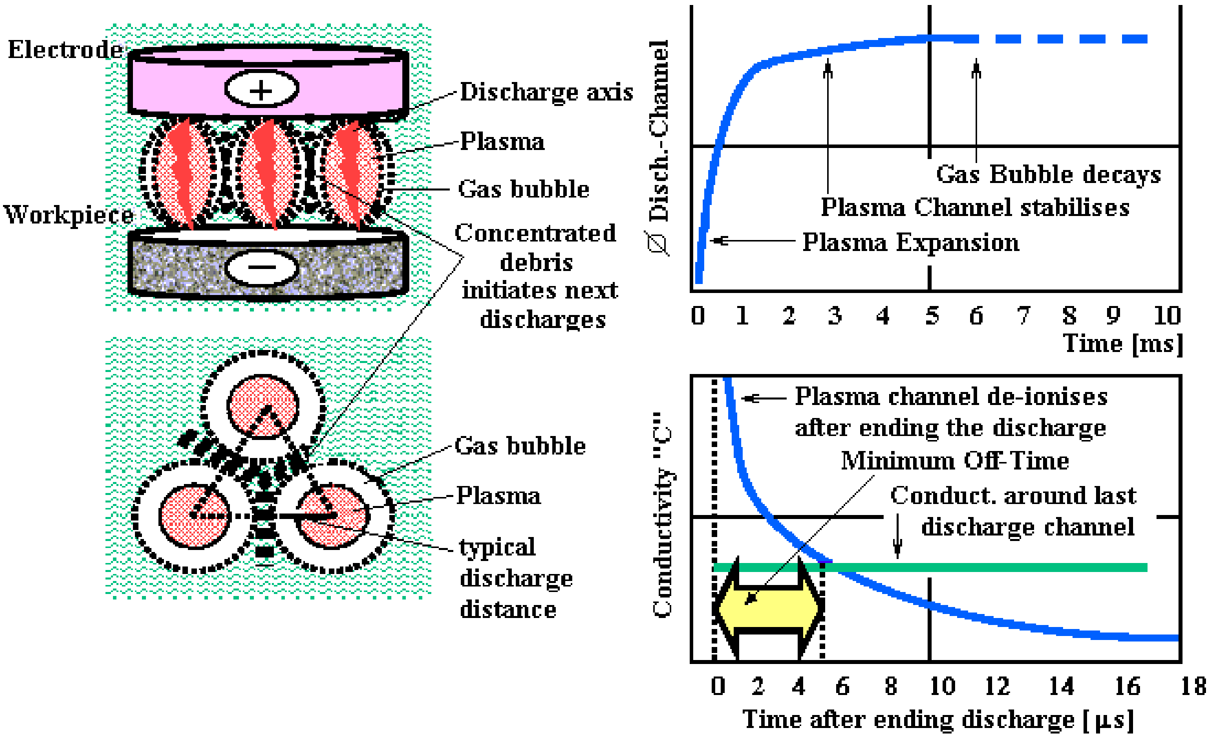

Fig. 2. Ignition conditions in the EDM Gap

This enlarged discharge channel is still under high pressure, as the liquid during evaporation multiplies its volume by factors of 20–40, depending from pressure level.

Most energy is now distributed to the cathode where the material at the plasma spots becomes only molten. During plasma oscillations metal may partwise be ejected at moments of pressure lowering, reported by A. Zingermann [4] as "flares".

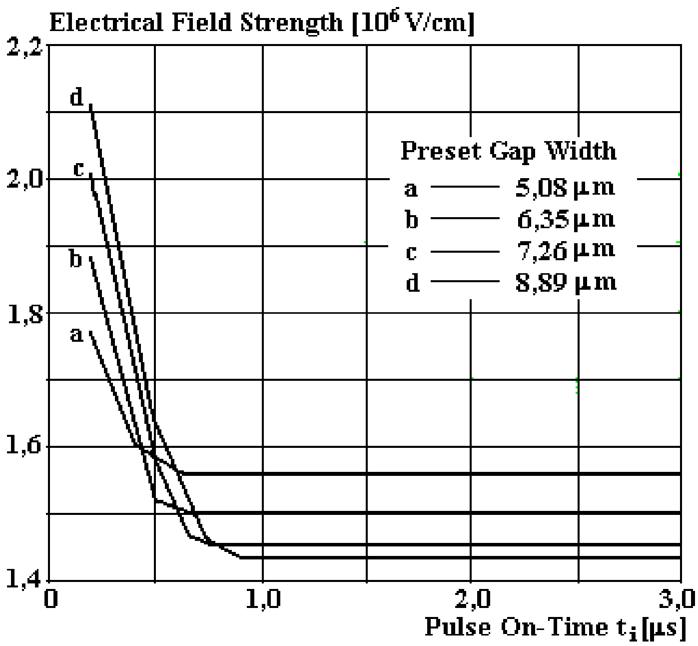

Fig. 3. Field Strength Need for Ignition

While running longer discharges the early electronprocess predominance changes later to positron-process predominance, which is reason to apply a change in electrode polarity when using longer on-times. Static pulse generators so connect the tool electrode to the anode. (Polarity shown also in Fig. 1).

Fig. 4 shows the front view of two different shaped discharge craters and beyond a crater cut-section taken by a touch probe. The left side refers to a pre-finishing condition with higher peak current and short on-time while the right side refers to roughing conditions with relative low discharge current and long spark endurance. The surface shows clear marking from the gas bubble around the active area of the discharge plasma. This roughing crater indicates also a plurality of crater shapes that may result from movements of the cathode spot and “flare” ejection [4] during moments of lowered pressure, when the plasma osszillates.

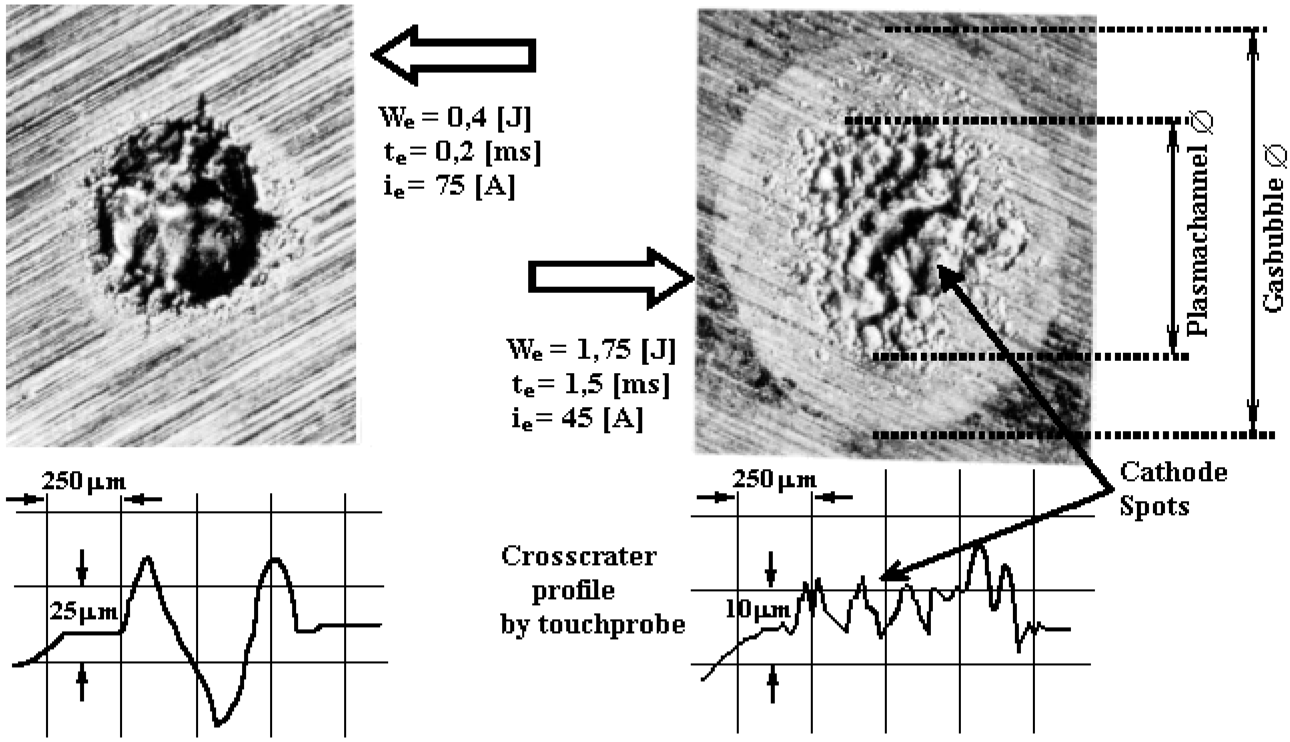

Fig. 4. EDM-Discharge; Shape of Crater

2.1.3. Interval phase between discharges

When the discharge is ended by switch off of the generator, the plasma channel de-ionises quickly. The gas bubble however stays quite long time in position. High speed photography [8, 12] indicate 25 times longer gas bubble life than on-time. With de-ionisation also pressure and temperature decrease in the plasma channel. The molten material at the electrode spots, overheated under the discharge pressure, now starts instantaneous boiling and ejection of liquid globules. When they enter the rather cool dielectric, they are shock hardened from outside and show afterwards hollow inner sections caused by further shrinkage of the metal. The debris concentration around earlier discharges create a conductivity level in the gap, which defines the minimum off-time to be respected before a new ignition can be started. This moment is normally reached after 5-15 microseconds when the de-ionisation level of the former plasma channel lowers beyond the average of gap conductivity (Fig. 2).

Fig. 5 reproduces a selected sequence of a photographic recording of discharges with a FASTAX WA4 high speed camera. This film is also available on a DVD+ Compact Disc. Discharges were organized in a glass chamber filled with clean dielectric between the tips of conic, round electrodes. The profile was illuminated by a strong light source from the back selected to register also the light resulting from the discharges. The electrodes were moved and the gap width respectively controlled by an electronic servo drive of a standard machine.

The film presentation shows bridge formations before ignition and also allows to recognize oscillations of the discharge channel during sparks. T. O. Hockenberry [12] registered similar films at Carnegie-Tech in Pittsburgh / USA (Fig. 6). He found another remarkable effect and reports, that the discharges shape their gas bubble in dependence to the geometric position. In narrow gaps they become quenched to a flat elliptic form while they form an ideal sphere in the liquid at gap corners.

3.1. EDM Servo Systems Control Discharges

The fact in all practical applications is, that machine operators when selecting the gap reference are in search for good discharge sequences and have to accept, that the gap width results to the selected machining parameters as well to flushing conditions in the gap, either forced by streaming liquid or jumping the electrode. The gap width, important factor for the creation of precise measure and shape in holes or engravings so ahs to be accepted only with rough estimate.

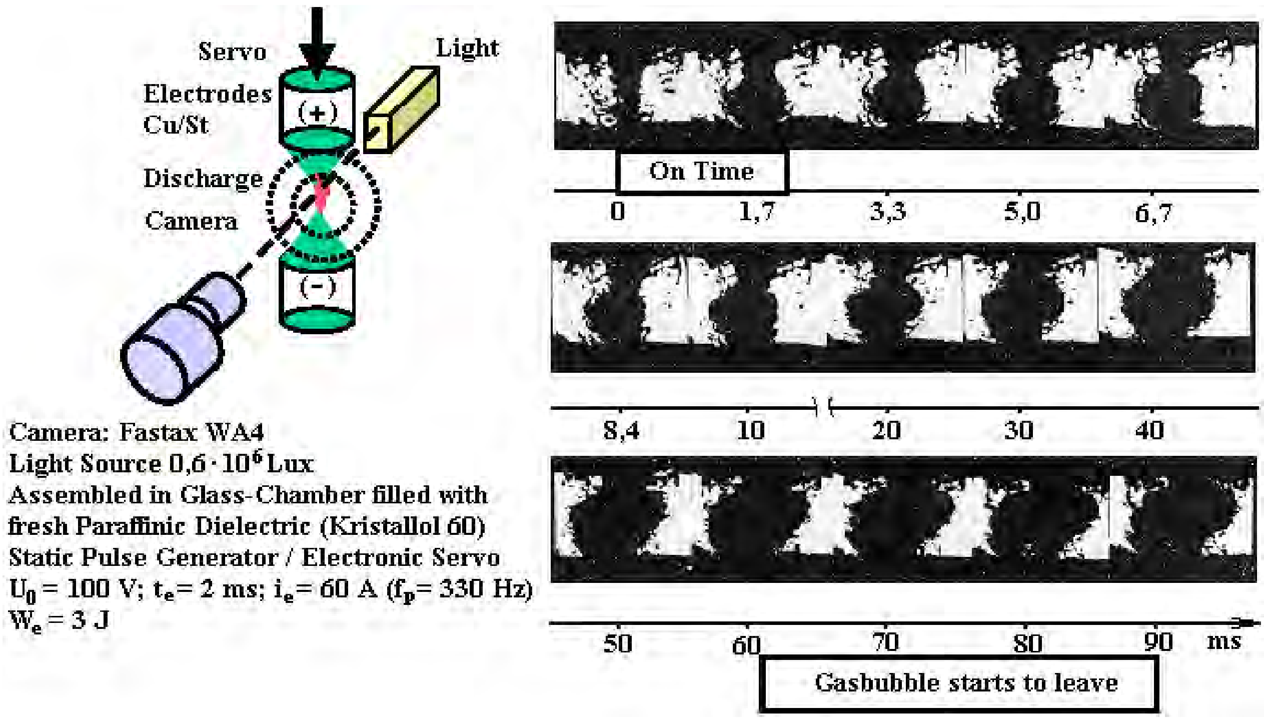

Fig. 5. Highspeed Photo Sequence (Fastax Camera)

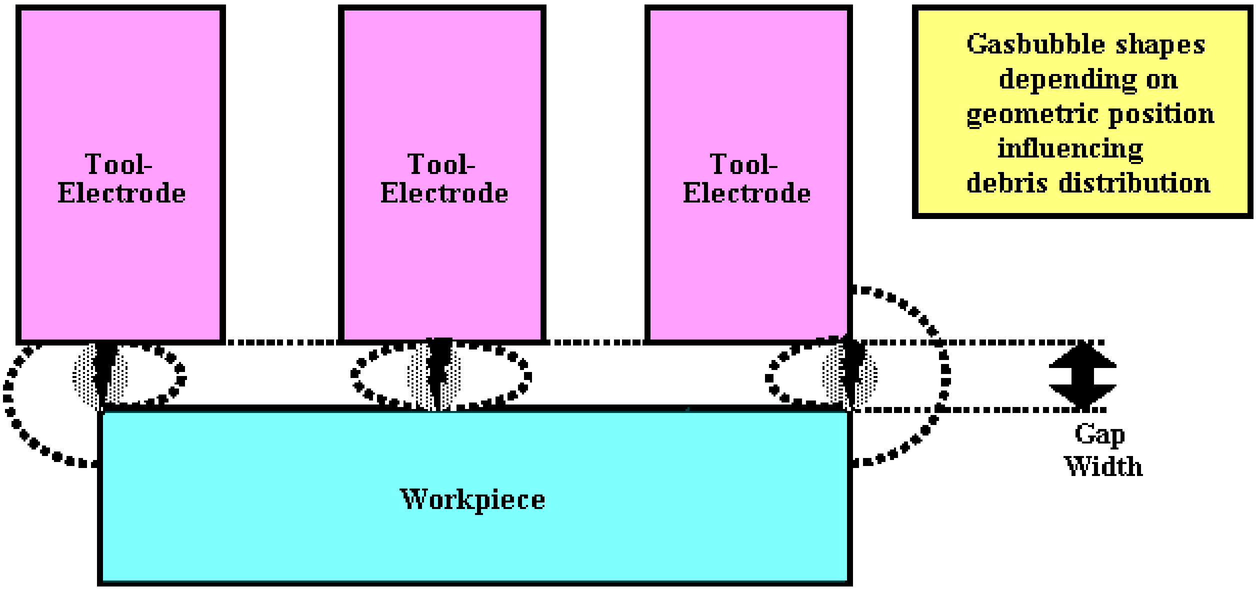

Fig. 6. Discharge Channel Shapes
(T.O. Hockenberry [12])

3.2. Gap Measurement Installation

The measurement of the real gap width in a running process is a procedure which need complicated equipment and is difficult as online process. In laboratory investigations it should however become common practice. The author proposed in the early sixties of the 20th century a method, which was also used for a wide investigation by E. Kracht [8, 10] The measuring principle is shown in Fig. 7.

Three different width of Gap are distinguished by this measurement.

The process has to be interrupted to clean the gap from debris to measure the Gap “a”. while the other measurement occur during the common machine operation. Special care has to be taken when measuring Gap “a” in proper cleaning and the fact, that in roughing condition the electrode surfaces reached contact by sensitive roughness peak *s*.

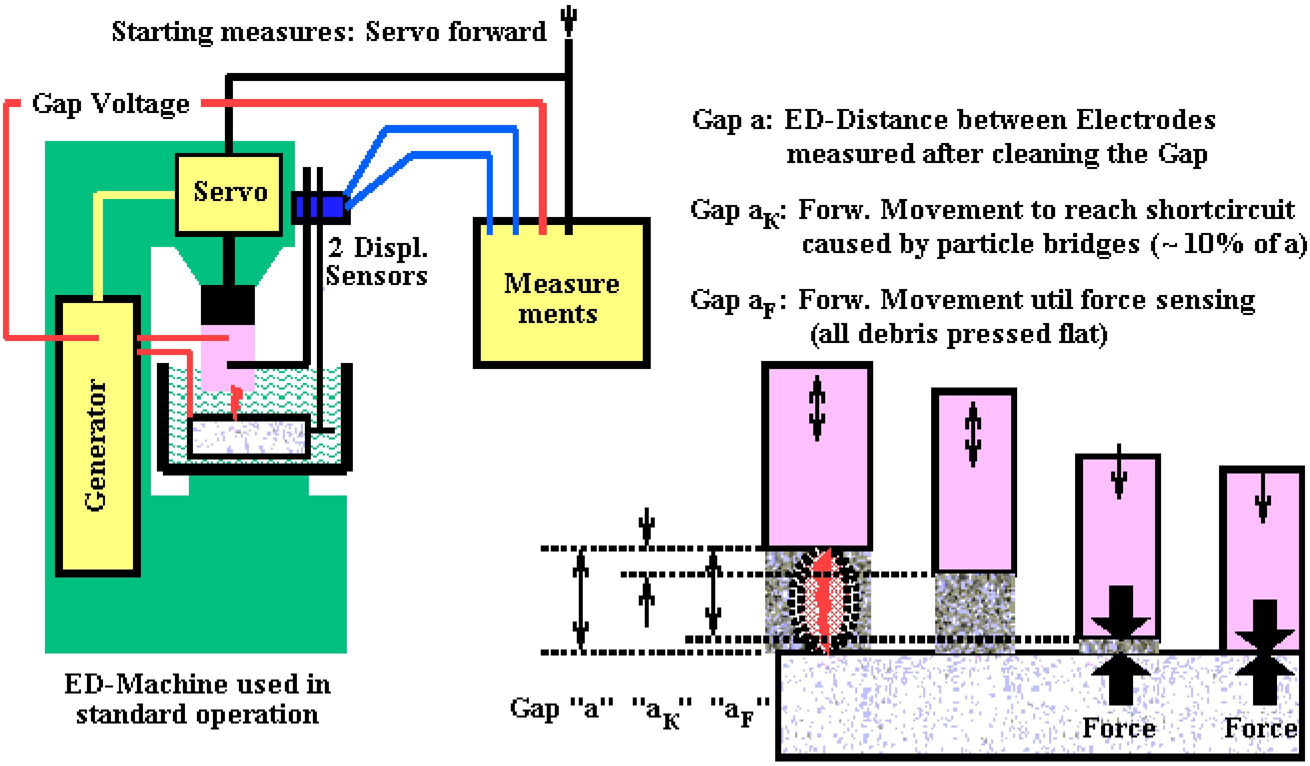

Fig. 7. Gap Measurement Installation

3.3 Gap Measurement Results

The measurements reported by E. Kracht [10, 14] are not reproduced here but only commented.

It can be generally stated, that gap width depend directly on the stock removal rates if not disturbed too much by engaged flushing. So in concordance with practical experience roughing results in much wider gaps then finishing. There is a second influence to shorten finishing gaps in the fact, that small finishing energies require short on-times. To avoid too much ignition delay, servo controls are set "closer" (see R. Crowe [5]).

Increasing discharge energy by stronger discharge current put gap with and stock removal rate progressively up and increases identically the wear rate.

Increasing discharge energy by longer on-times does not allow high discharge frequencies and causes more energy losses by heat conduction. Gap width and stock removal rate increase digressively while the wear rate becomes very small down to less than 0,3 %.

Increasing the pause time puts the servo controller more an more in trouble, but the quantity of discharges results in an proportional gap with as also stock removal rate. The wear rate behaves different. Where stock removal rate is high ("good" debris production in the gap) the servo acts properly and wear rate is advantageous.

The gap measurements results show impressively, that a good interpretation of the EDM process needs knowledge of the real gap dimensions which should be measured at least for systematic investigation on the behaviour of stock removal and volumetric wear rates.

4. SUMMARY

60 years passed since the proposal to use electrical discharges as a machining technology. This paper takes again the occasion to propose, divergent to common reported explanations of discharge ignition for EDM, a theory, that stipulates the formation of particle bridges as discharge ignition phenomena.

A method is reported, how gap with measurements could become continuously introduced in machining procedures to allow a more comprehensive interpretation of the working parameters of the process. This is especially important for the gap, as servo settings, though reported to define the gap width, are in practice only defining discharge conditions.

The author wants to compliment the Russian researches, in part friends and dear colleagues for their continuous engagement and enthusiasm to the interpretation and application of electrical discharge machin-

ing – EDM – as meanwhile a renown and world wide important manufacturing process, especially for the production of special toolings.

REFERENCES

1. *Lazarenko B.R.* About the Inversion of Metal Erosion and Methods to Fight Ravage of Electric Contacts. Moscow, WEI Institute, 1943 (in Russian).
2. *Drabkina, S.J.* Theory on the Development of the Discharge Channel in Electroerosion // Journal of Exp.Theor. Phys. 1951. V. 21. № 4. P. 473–483. (in Russian).
3. *Zolotych B.N.* Fundamental Physics of Electroerosion on Metals. Moscow, 1953. (in Russian).
4. *Zingermann A.S.* About the Development of the Discharge Channel in Electroerosive Metal Machining. Journal Techn. Phys. 1956. V. 26. № 5. P. 1015–1020. (in Russian).
5. *Crowe R.W.* Formative Timelags in the Electric Breakdown of Liquid Hydrocarbons // Journal of Applied Phys. 1956. V. 27. № 2. P. 156–160.
6. *Stavitskii B.I., Bezruk A.I.* Effects of the Electrode Gap on Erosion and on the Energy Distribution Between Anode and Cathode. (Transl. from Russian by Consultants New York UDC 621.9.048.4) orig: Elektronnaya Obrabotka Materialov. 1969. № 5. P. 7–13.
7. *Wertheim R.*. Investigation on Energetic Reactions of Sparkmachining as Basis to Process Improvements. Thesis RWTH Aachen. 1975. (in German).
8. *Schumacher B.M.* Removal Behavior and Wear when Sparkeroding Steel with Storage – and Staticswitch-pulse Generators. Thesis RWTH Aachen 1965. (in German).
9. *Müeller H.* Contribution to Spark-Erosion Phenomena. Elektrowärme. 1965. V. 23. № 3. (in German).
10. *Kracht E.* Fundamentals of Metalerosion by Spark Discharges Thesis RWTH Aachen. 1970. (in German).
11. *Zolotych B.N.* The Relation Between Surface Roughness and Crater-Shape in Electroerosive Metal Machining // Vestnik mashinostroenja. 1959. №10. P. 58–61. (in Russian).
12. *Hockenberry T.O.*. Geometrical Formation of the Discharge Channel in Narrow Gaps. SME-paper. 1967.
13. *Barz E.* Strategies to Self-Optimation of Sparkerosive Diesinking. Thesis RWTH Aachen. 1976. (in German).
14. *Schumacher B.M.* About the Role of Debris in the Gap During Electrical Discharge Machining // Annals of CIRP. 1990. V. 39. № 1.

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Summary

The ignition of electrical discharges in the dirty liquid filled gap, when applying EDM, is mostly interpreted identical as found in the physical research of discharges in air (Lichtenberg Figures) or in vacuum (Radio Tubes) as well as with investigations on the breakthrough strength of insulating hydrocarbon liquids. The servo controlled variable gap in real ED-Machining however differs very much from such condition. The author stipulates ignition of electrical discharges by the evaporation of particle bridges in the gap through excessive current. The ignition spot in the process area is conditioned by the remaining particles, removed from the electrodes, as well as gas bubbles from former discharges. The material removal procedure is grouped in an evaporation phase at start of ignition and later in the ejection of fused material by instantaneous boiling at the discharge spots. The gap width should be measured during all investigations on discharge parameters, because it changes in dependence from stock removal rates, while servo controllers only stabilise the average process.