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Important facts about spark erosion

Human Technology
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HUTEC

Philipp and Martin Storr • Managing Directors

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oelheld is a medium-sized company, which has more than 130 years of tradition and experience. Since the foundation in 1887 by Carl Christian Held, oelheld has become an established specialist for lubricants. Partnerships, research, and human resources technology have grown as a valuable tradition of which we are proud of.

Numerous customers and machine manufacturers along with national and international universities have partnered with us to develop high quality lubricants. Through this cooperation we are able to focus intensively on meeting and adjusting to specific requirements on a wide range of different manufacturing processes. Our laboratories are equipped with state-of-the-art analytical equipment and numerous application testing systems that guarantee today's demanding requirements, and many of tomorrow's ever changing new standards.

„**Innovative product development, strengthened by continuous quality control and comprehensive customer service, is the key to the success of our products.**"

Human Technology

Innovations for man, environment and machines

Hutec is our main focus in the development and production of our products. It is also our mission statement in our use of resources and ever present at oelheld.

What does this mean?

- REACH requirements are fulfilled
- Skin reviews and approvals available for most products
- Low emission and aromatics free / low aromatic products
- Products free of heavy metal
- State-of-the-art production facilities
- Environmentally friendly production processes
- Products are tested for compatibility with machine components
- Sustainability in the selection of raw materials
- Environmentally friendly and resource-saving products

Human Technology
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Content

1. Technology of spark erosion

Introduction

Spark erosion is a modern machining process that offers decisive advantages and is being used to an ever greater extent. A practical example is the countless possibilities in metalworking. A press mould for glassware. The ejector opening in the bottom. The suitable ejector next to it. Both eroded in a single operation. A difficult workpiece, quickly and precisely machined. But how does it all work? How can you imagine removal with spark erosion? Unfortunately, most processes are not visible. Let's try to get an idea with models and schemas.

The principle

The principle of die-sinking EDM is simple. Workpiece and tool are positioned very closely but do not touch each other. A gap remains, which is filled with an insulating liquid. Machining is therefore carried out in a container. Workpiece and tool are connected to a DC power source via cables. A switch is located in a line. When the switch is closed, electrical voltage is generated between the workpiece and the tool. Initially, no current flows because the dielectric insulates the workpiece and the tool. If the gap is then reduced, a spark strikes at a certain, very small distance. In this process, also known as discharge, electricity is converted into heat. The material surface heats up very strongly in the area of the discharge channel. If the current flow is now interrupted, the discharge channel collapses very quickly. This causes the molten metal on the material surface to evaporate explosively and tears liquid material along to a certain depth. A small crater forms. If every discharge is followed by another discharge, craters form next to craters and the workpiece surface is constantly eroded. (Figure 1)
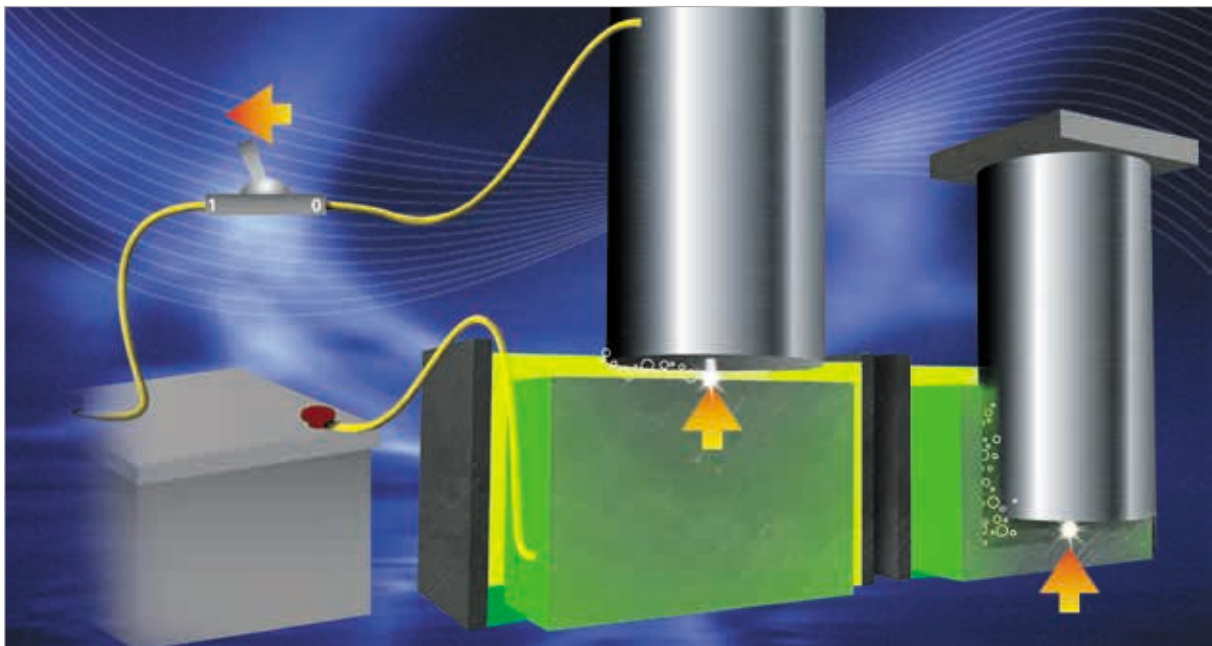

Figure 1

Spark gap

The voltage applied to the electrode and workpiece and the discharge current have a time sequence which is shown under the illustrations of the individual phases. Starting from the left, the voltage builds up an electric field throughout the space between the electrodes. As a result of the power of the field and the geometrical characteristics of the surfaces, conductive particles suspended in the fluid concentrate at the point where the field is strongest. This results in a bridge being formed, as can be seen in the center of the picture. At the same time negatively charged particles are emitted from the negatively charged electrode. They collide with neutral particles in the space between the electrodes and are split. Thus positively and negatively charged particles are formed. This process spreads at an explosive rate and is known as impact ionization. This development is encouraged by bridges of conductive particles. (Figure 2)
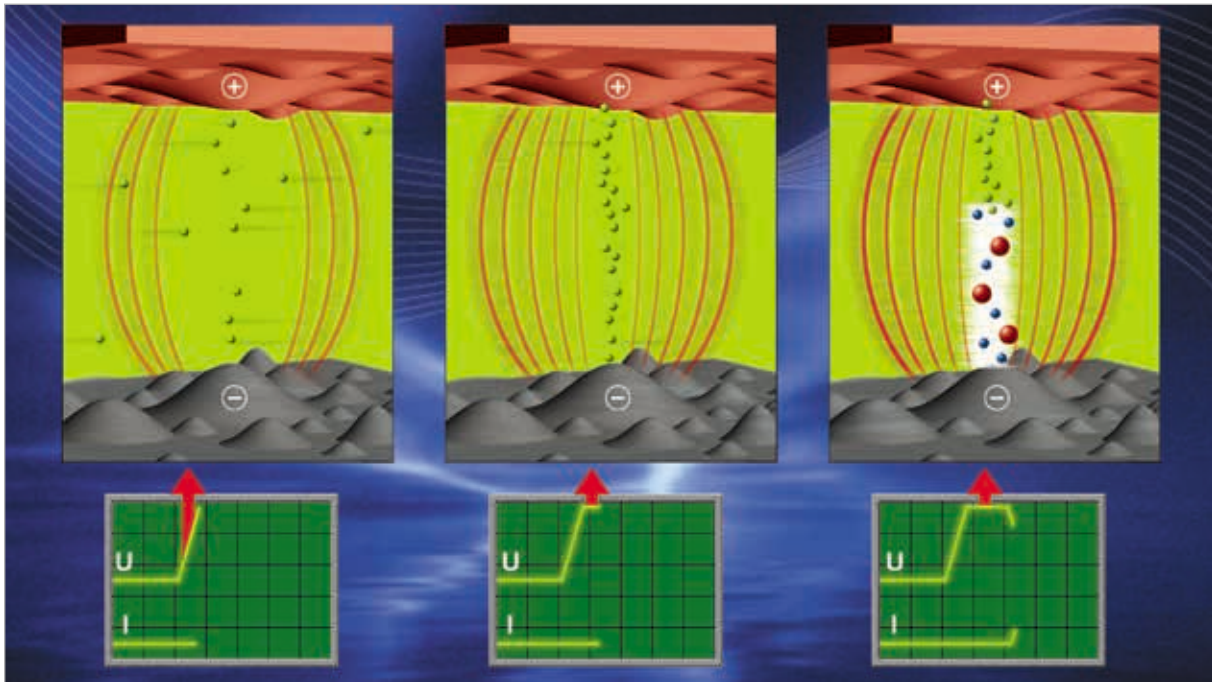
Figure 2

Here we see what is in fact invisible. The positively charged particles migrate to the negative electrode, and the negative particles go to positive. An electric current flows. This current increases to a maximum, and the temperature and pressure increase further. The bubble of vapour expands, as can be seen in Figure 3.
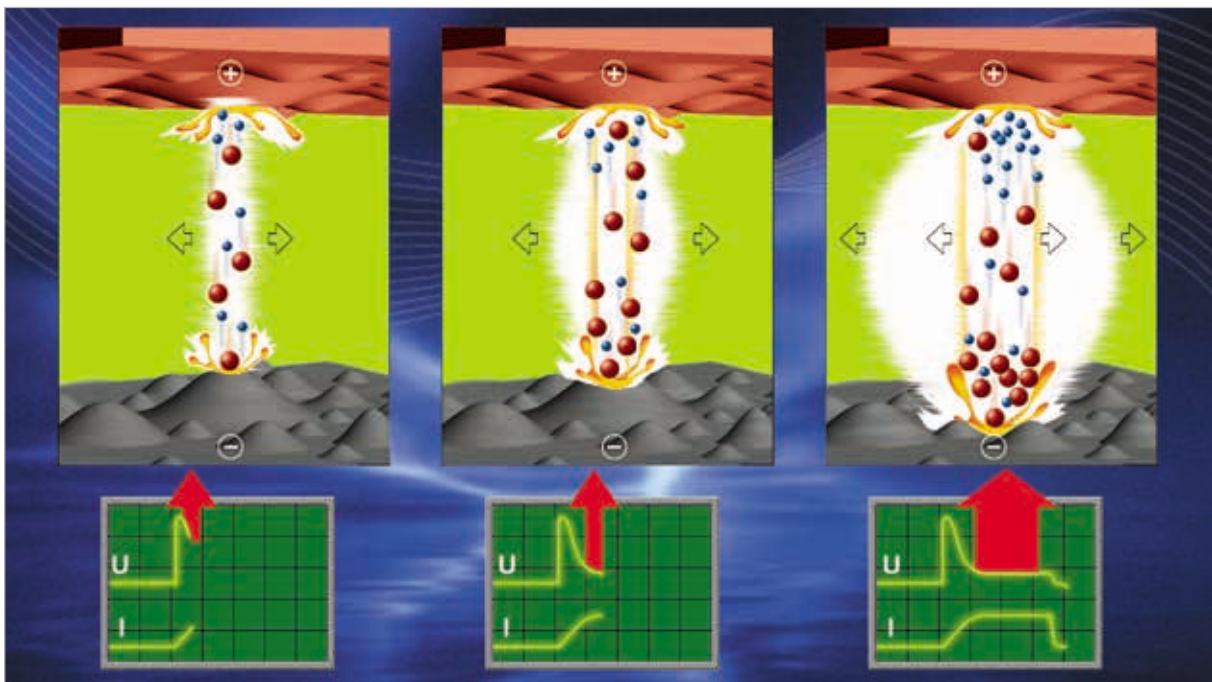

Figure 3

Connection between the path of electric power and heat

The model shows how the supply of heat is reduced by a drop in current. The number of electrically charged particles declines rapidly and the pressure collapses together with the discharge channel. The overheated molten metal evaporates explosively, taking molten material with it. The vapour bubble then also collapses and metal particles and breakdown products from the working fluid remain as residue. These are mainly graphite and gas. (Figure 4)
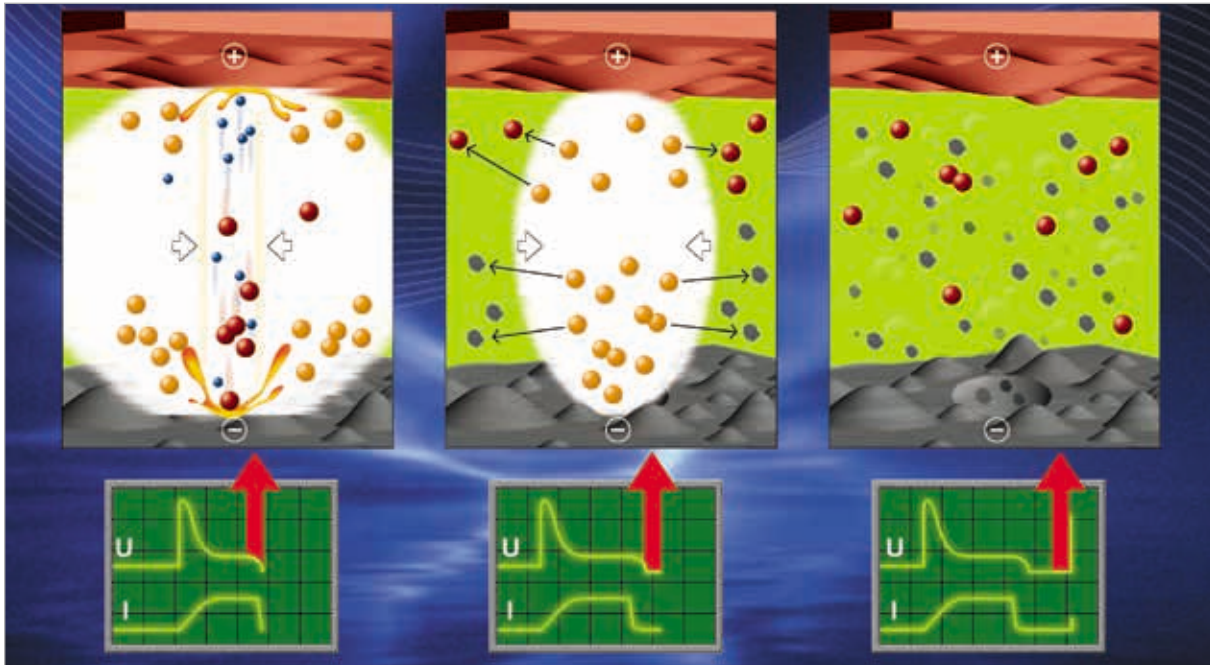

Figure 4

By means of the model we will now demonstrate the relationship between the flow of current and heat. In the detail enlargement below we see the negative electrode surface and part of the discharge channel above it. Positively charged particles strike the surface of the metal. These are shown in red. They impart strong vibrations to particles of metal, which correspond to a rise in temperature. When a sufficient velocity is reached, particles of metal, which are shown in grey and yellow, can be torn out. A combination of positively charged particles, shown in red, and negatively charged particles, shown in blue, augments the vibration and thus raises the temperature of the particles, which are now uncharged. (Figure 5)
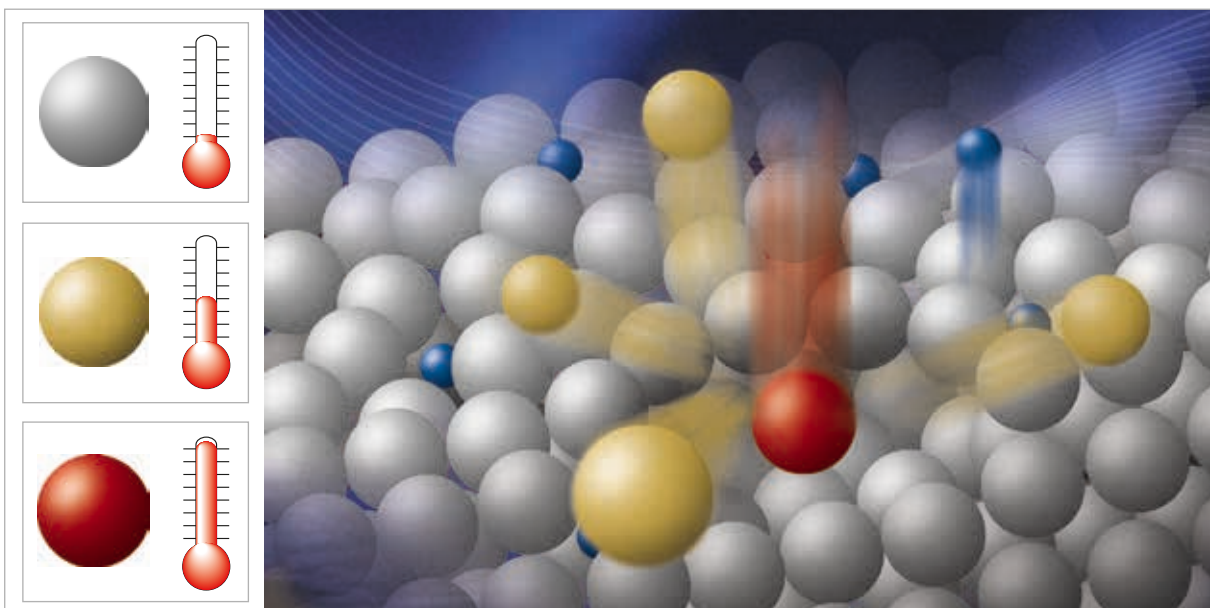

Figure 5

We know that electrical energy is converted into heat when the discharge takes place. This maintains the discharge channel, leads to the formation of discharge craters on the electrodes, and raises the temperature of the dielectric. (Figure 6)
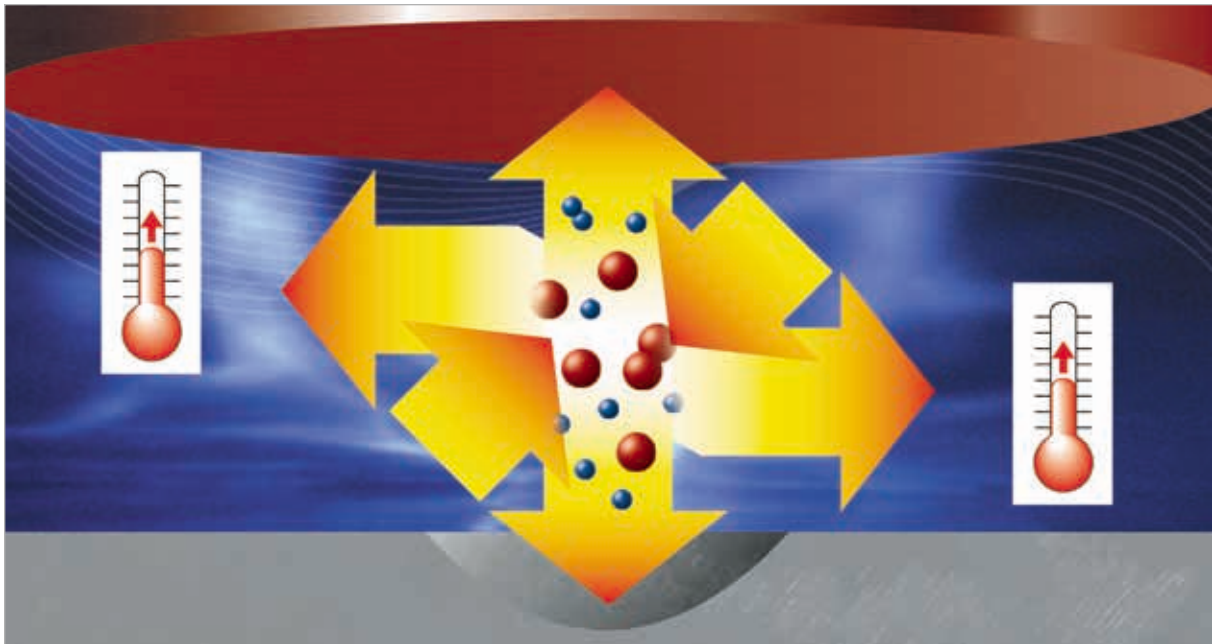

Figure 6

Polarity

Now let us examine the question of polarity. The exchange of negatively and positively charged particles, which are respectively shown in blue or red, results in a flow of current in the discharge channel. The particles thus generate heat which causes the metal to melt. With a very short pulse duration more negative than positive particles are in motion. The more particles of one kind move towards the target electrode, the more heat is generated on it. It is also important that as a result of their greater size the positively charged particles generate more heat with the same impact velocity. In order to minimize the material removal or wear on the tool electrode, the polarity is selected so that as much heat as possible is liberated on the workpiece by the time the discharge comes to an end. With short pulses the tool electrode is therefore connected to the negative pole. Its polarity is thus negative.
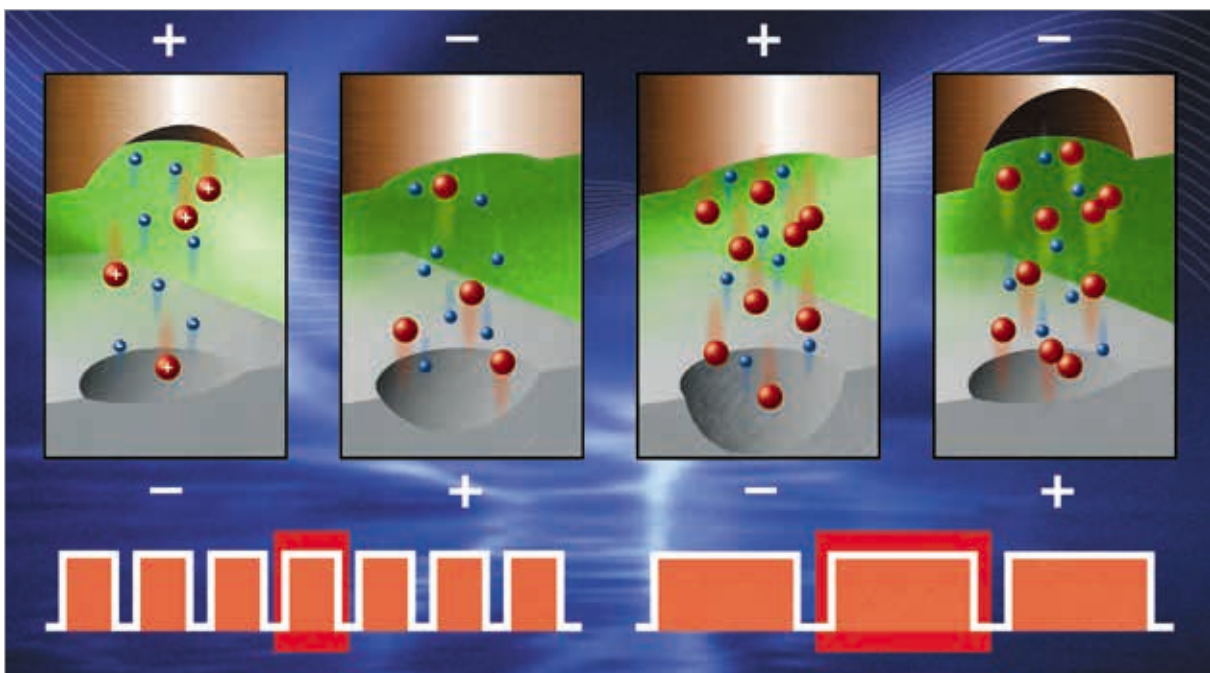

Figure 7

With long pulses, however, it is connected to the positive pole so that its polarity is positive. The pulse duration at which the polarity is changed depends upon a number of factors which are mainly connected to the physical characteristics of the tool and electrode materials. When steel is cut with copper the marginal pulse duration is about 5 microseconds. (Figure 7)

Machining time

In spark erosion, with all machining processes, time and accuracy are important factors. The erosion time is determined by the volume of material to be removed from the workpiece and the rate of removal, which is represented by Vw. This is measured in cubic millimetres per minute or cubic inches per hour. The wear on the tool electrode is another factor influencing the machining accuracy. It is represented by a small Greek theta (ϑ) and a v. This figure is the volume of material lost from the electrode by wear, expressed as a percentage of the volume removed from the workpiece. (Figure 8)
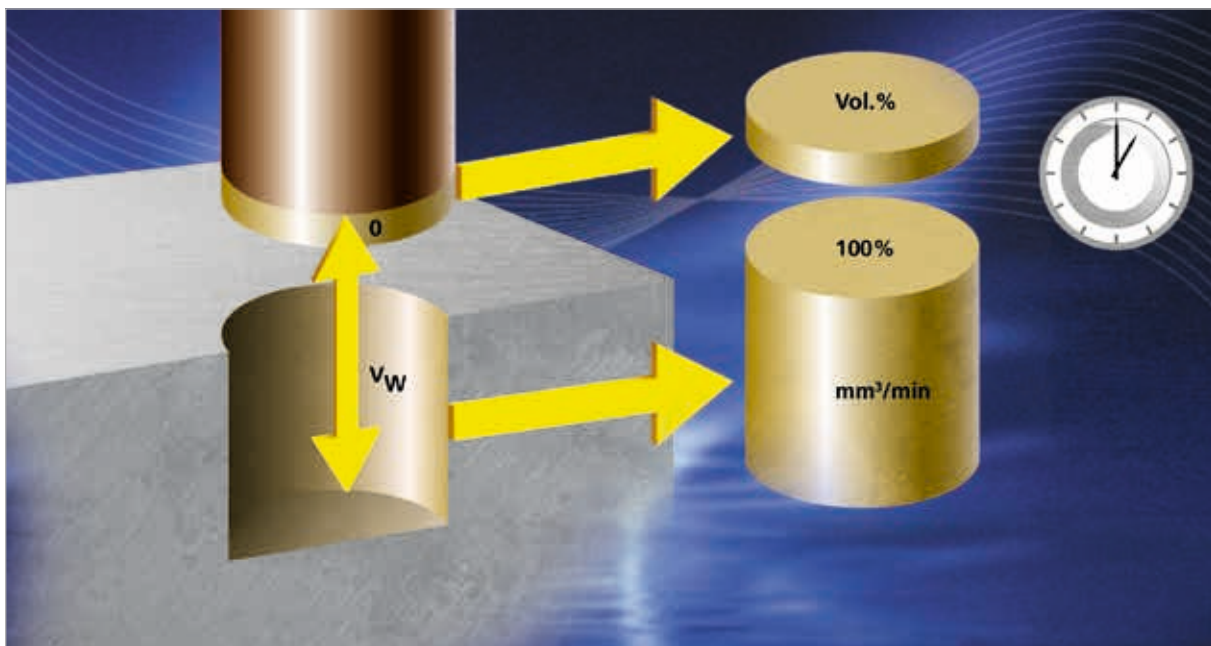

Figure 8

Surface finish

In a similar way to conventional machining methods, spark erosion does not produce a completely smooth surface but a slightly rough, indented one. This surface is typical of spark erosion and its quality must be known for the function or fitting of individual workpieces. For the purpose of measurement a reference system and surface dimensions have been created so as to allow the surface quality to be specified. Frequently used measurements and characteristics are Rmax and Ra. Rmax represents the greatest roughness height. In Germany and France this value is also known as Rt, and in the USA it is known as Hmax. Rmax becomes an important characteristic if, for example, a part has to be polished or lapped. The arithmetical mean roughness is represented by CLA in Britain. This value is always important when a part is being machined in order to achieve a fit. In the USA it is represented by AA, and in Switzerland by Ra. (Figure 9)
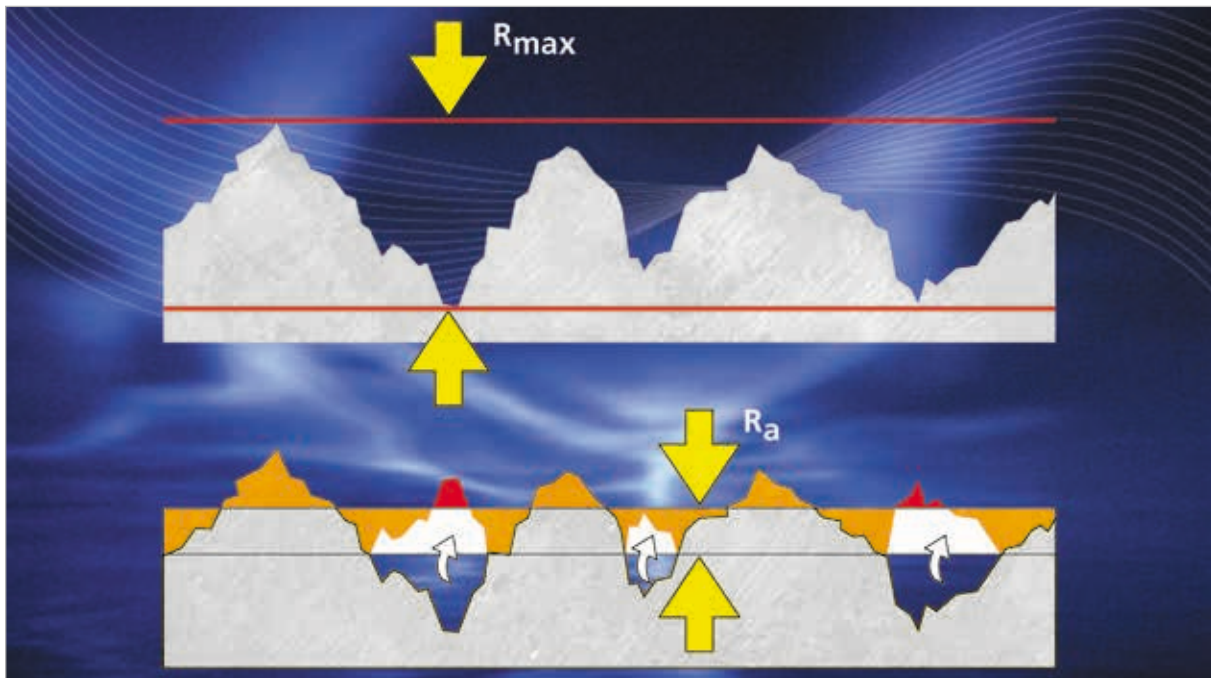

Figure 9

In exactly the same way as with cutting operations, fine or coarse surfaces can be produced by erosion. The following two examples show how wide a range of roughness the eroded surface can have (Figure10)

Figure 10

Different spark gaps

The spark gap separates the workpiece from the tool electrode. Even at a small cutting depth a distinction must be made between the frontal and the lateral gap. The frontal gap is determined by the control system, while the lateral gap depends upon the duration and height of the discharge pulses, the combination of materials, the no-load voltage and other predetermined values. (Figure 11)
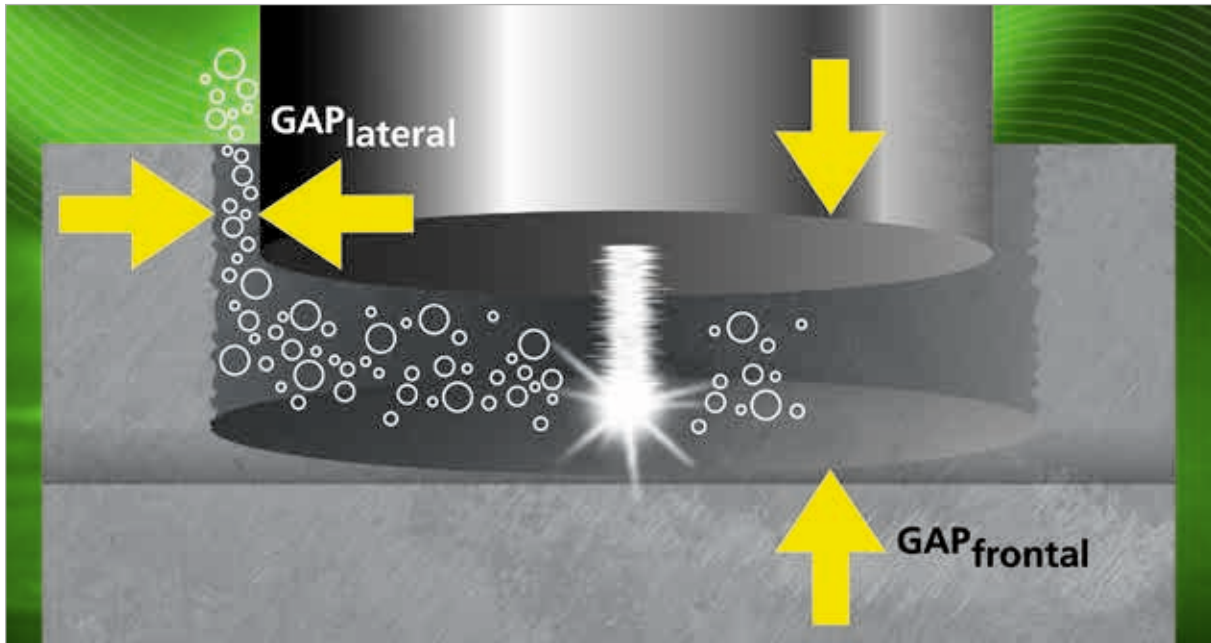

Figure 11

Power supply unit

The power supply unit is an important part of any spark erosion system. It transforms the AC supply from the mains and provides rectangular voltage pulses. This can visualized by plotting a graph of voltage against time. The size of the rectangles and the distance between them can be adapted to any operational requirements. (Figure 12)
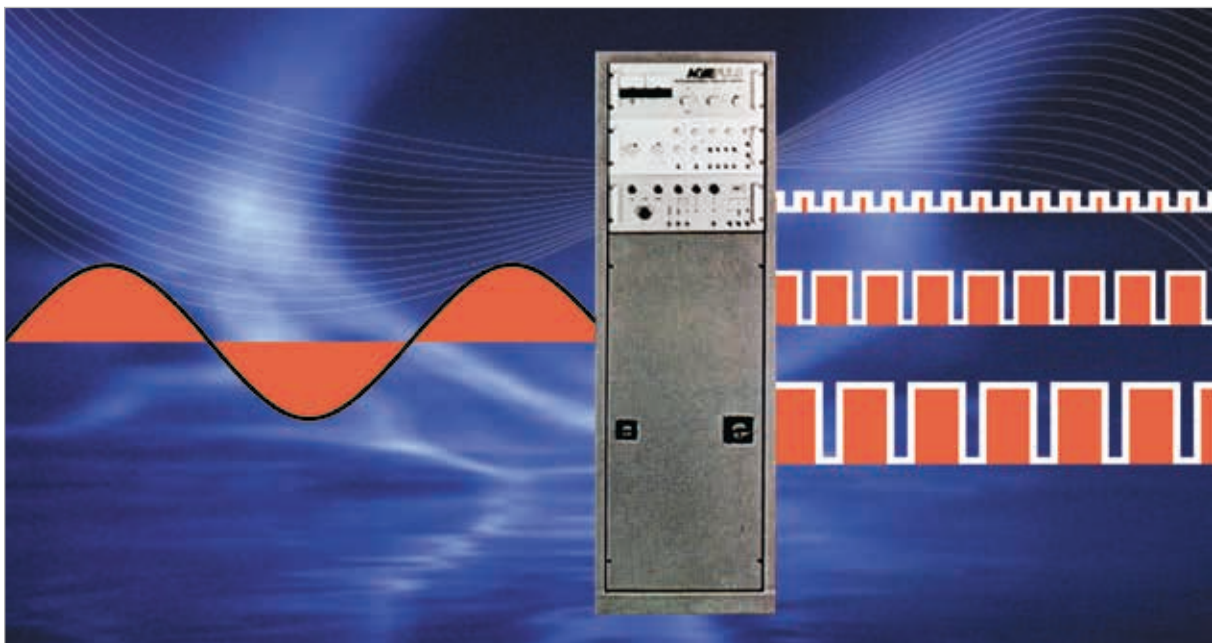

Figure 12

The sequence of the rectangle is a graphic representation of the opening and closing of the switch, or in other words the pulse duration and pulse interval, or of the discharge time and pause, and also of the voltage and current at the spark gap. In the AGIEPULS-L power supply units the discharge current, pulse duration and pulse interval can be set completely independently of each other. The discharge current is proportional to the height of the rectangle, and the width corresponds to the pulse duration, which is measured in micro seconds or millionths of a second. The distance between the individual pulses can also be altered so as to set the length of the intervals during which the flow of current is interrupted. The pulse interval is expressed as a percentage of the pulse duration. For example, if the interval lasts 25 micro seconds and the pulse 100 micro seconds, Tau is 80 per cent. This means that the pulse lasts for 80 per cent of a switching cycle and the interval for 20 percent of the cycle. (Figure 13)

Figure 13

Electrode wear

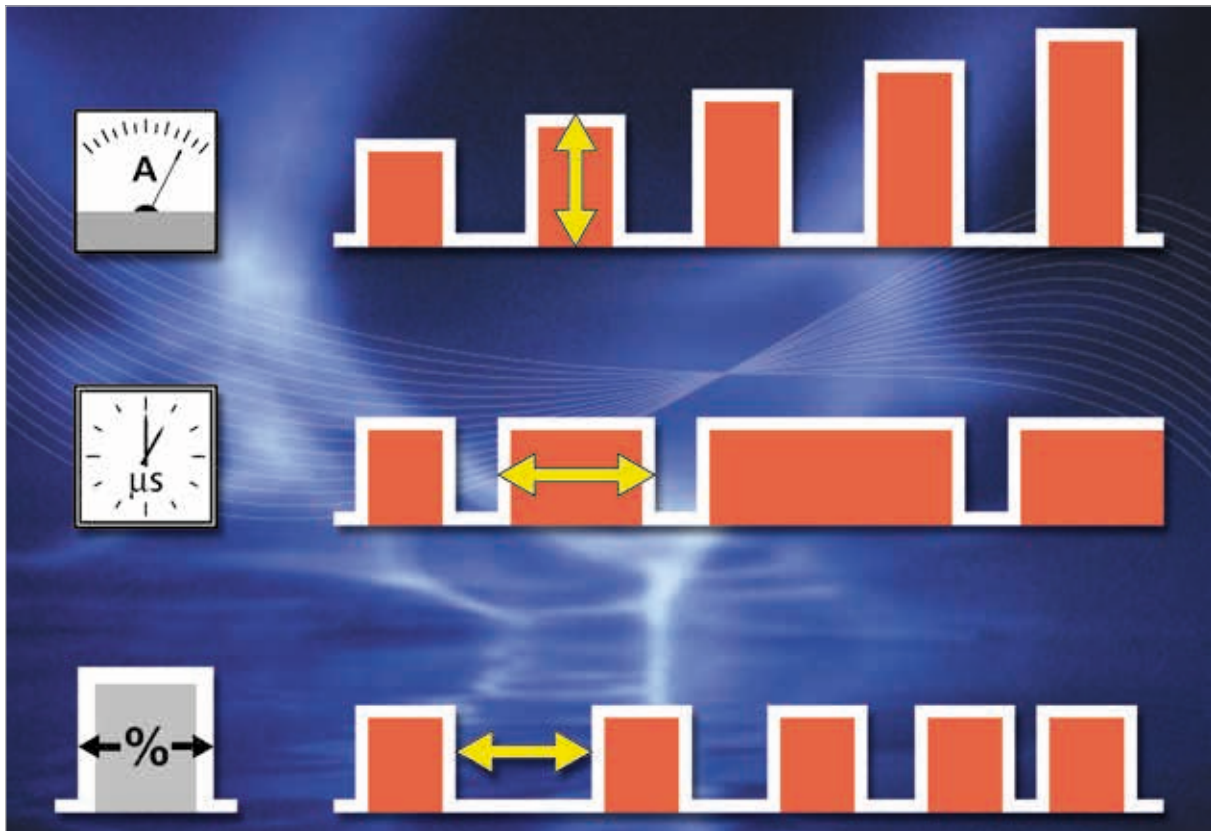Erosion with a light current gives a low rate of removal, while conversely a heavy current gives a high rate of removal. But the wear on the tool electrode expressed as a percentage of the volume also increases if steel workpieces are eroded with copper electrodes. Graphite electrodes behave differently. The wear declines up to a certain current level and then remains more or less constant. (Figure 14)
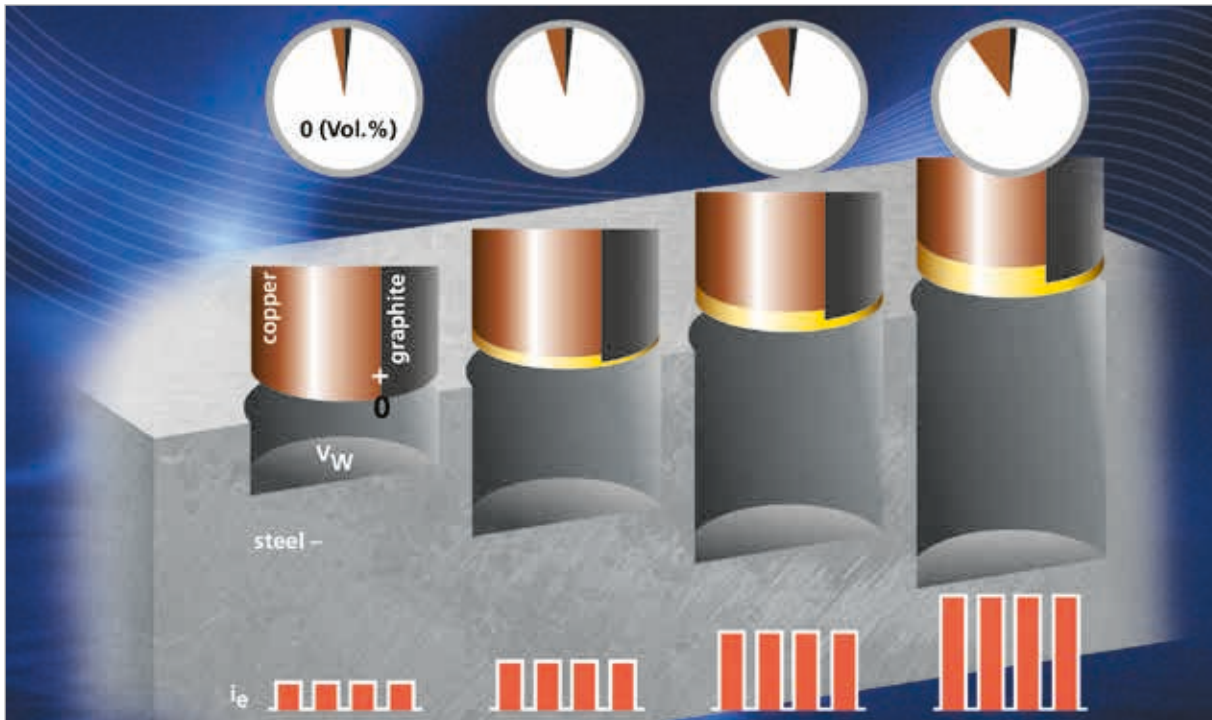
Figure 14

Eroding with short pulses means increasing electrode wear. Conversely the wear is smaller when the pulses are long. In practice, when roughing steel with copper and graphite electrodes a pulse length in between maximum removal and minimum wear is selected. (Figure15)
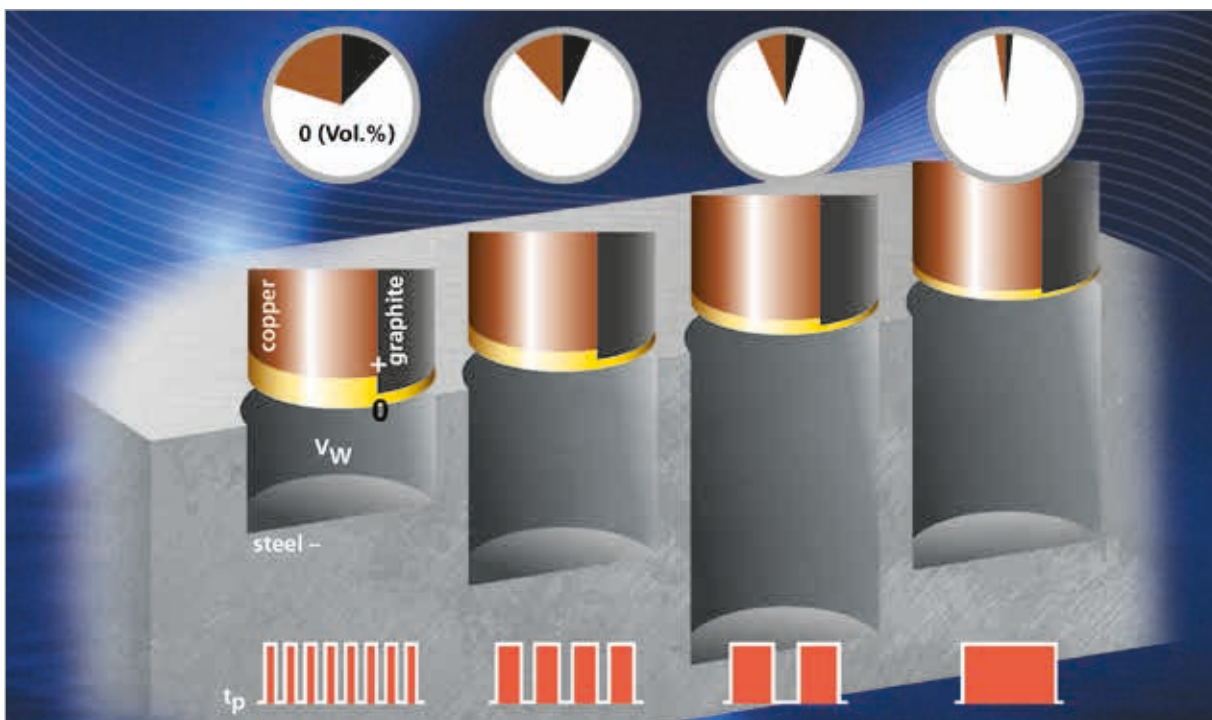
Figure 15

Off time

Not least, the interval between two discharges is a factor of considerable importance. In general rapid removal with little wear can be achieved with small intervals, or in other words a high duty factor. The limit must not be exceeded because a point is then reached beyond which the process is impaired resulting in reduced erosion and greater wear. This critical value is also known as the marginal duty factor. (Figure 16)
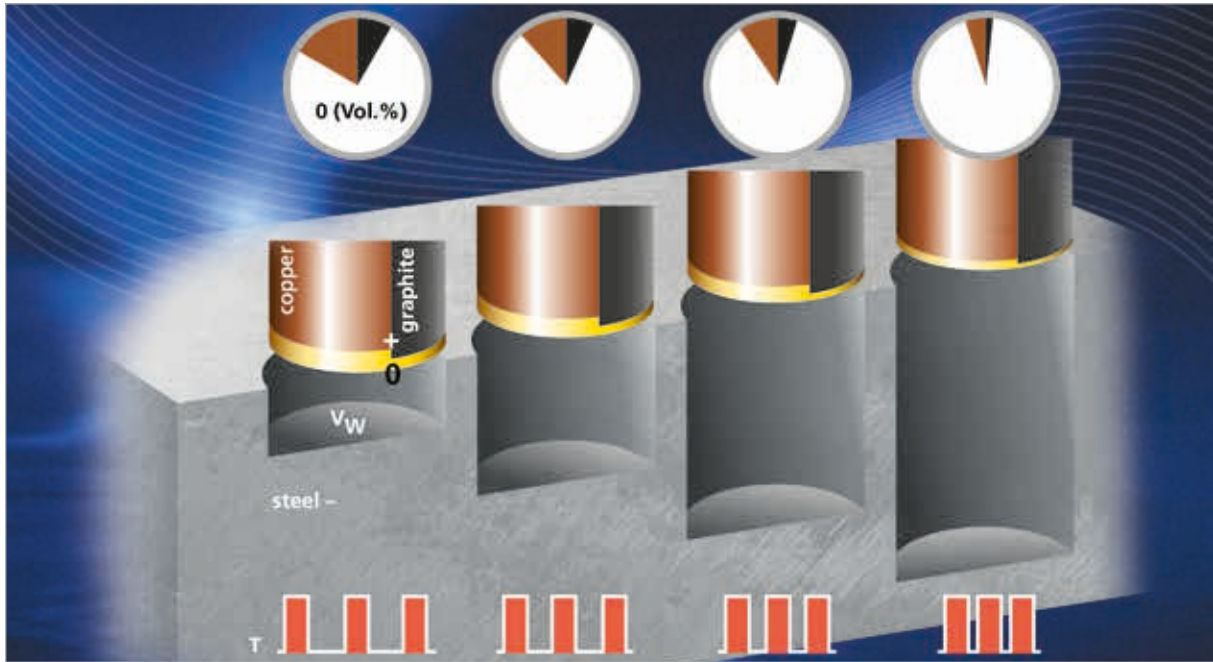
Figure 16

Impulse current

This diagram shows that the surface roughness and the size of the spark gap are decisively influenced by the discharge energy, which is represented by the area of a current pulse in the picture. The energy contained in a pulse is proportional to the orange-coloured area. It can clearly be seen that the roughness is less marked with low discharge energy than high discharge energy. For example, in pre-finishing and finishing a certain surface quality must be attained. This corresponds to a given discharge energy which must be found by suitable adjustment of the discharge current or pulse height and the discharge time or pulse width A compromise between maximum erosion and minimum wear is chosen from the range of possible settings. (Figure 17)
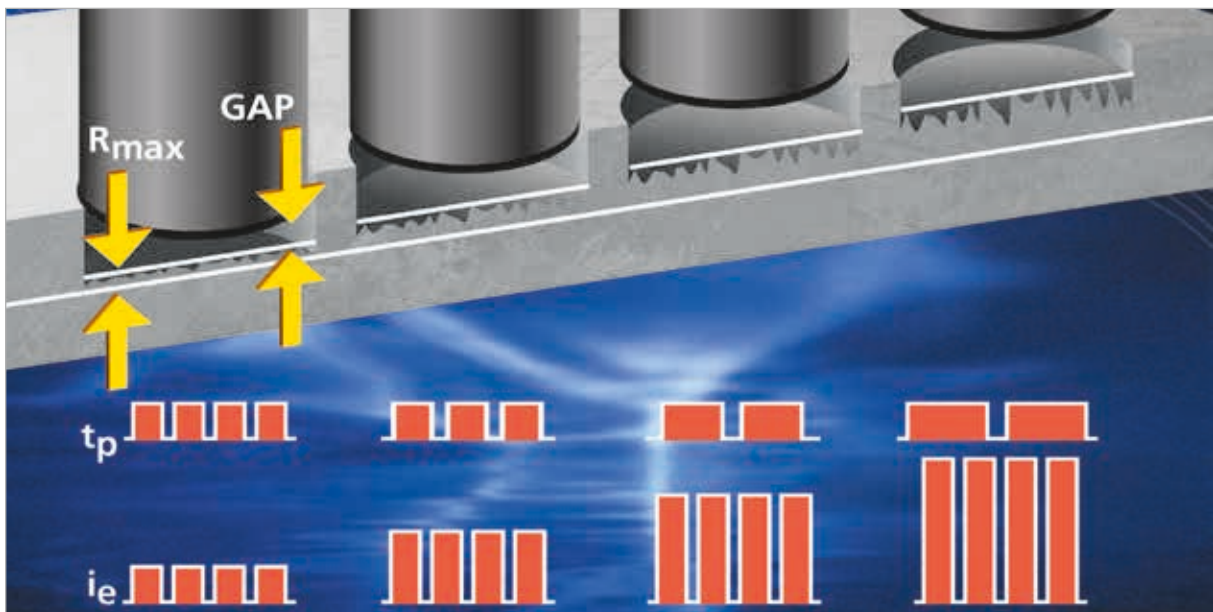
Figure 17

Surface quality in relation to current

A rougher surface is machined to a finer one by eroding with reduced discharge energy. The roughness is reduced, while the electrode wear is somewhat increased. The picture shows how big a difference there can be in practice between two subsequent machining stages. (Figure 18)
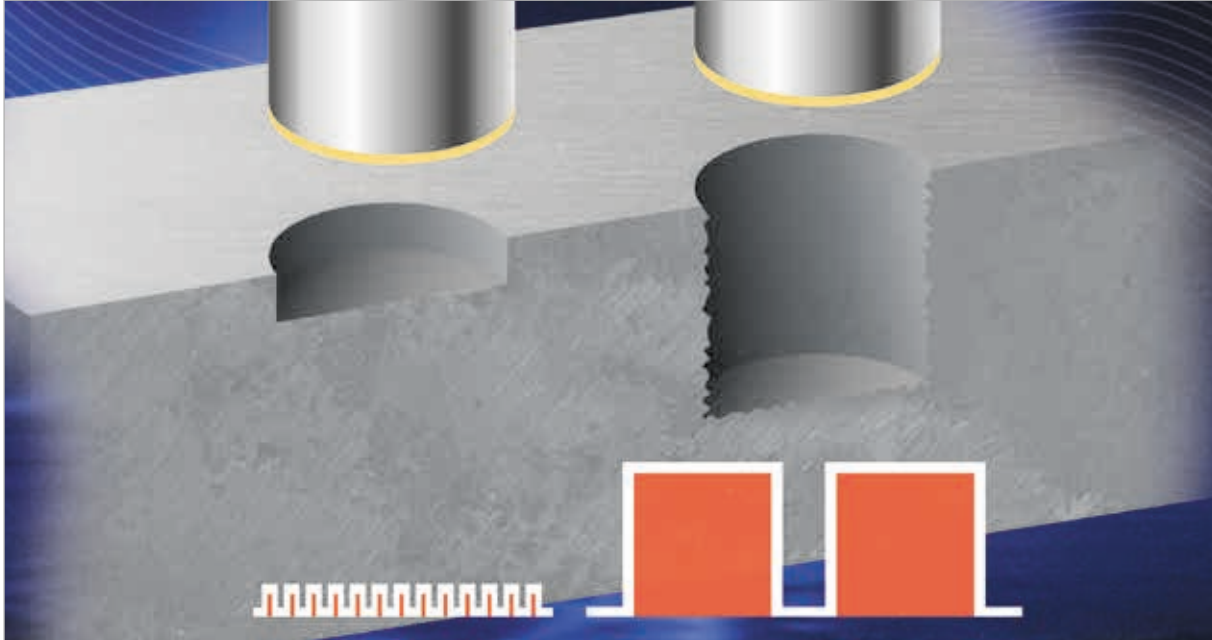
Figure 18

In workshop practice, in roughing or pre-machining a degree of roughness should be attained which needs only to be evened out in the next machining stage. Experience has shown that the roughness of the subsequent stage is about a third to a fifth of the initial roughness. This procedure gives a very economic overall eroding time in relation to the degree of accuracy attained. (Figure 19)

Figure 19

2. The use of Dielectrics in spark erosion

In 1943 the Russian research scientists, Mr. and Mrs. B. R. and N. J. Lazarenko, discovered that the erosive effect of capacitor discharges could be utilized in the processing of metals. At first they used ordinary air as a die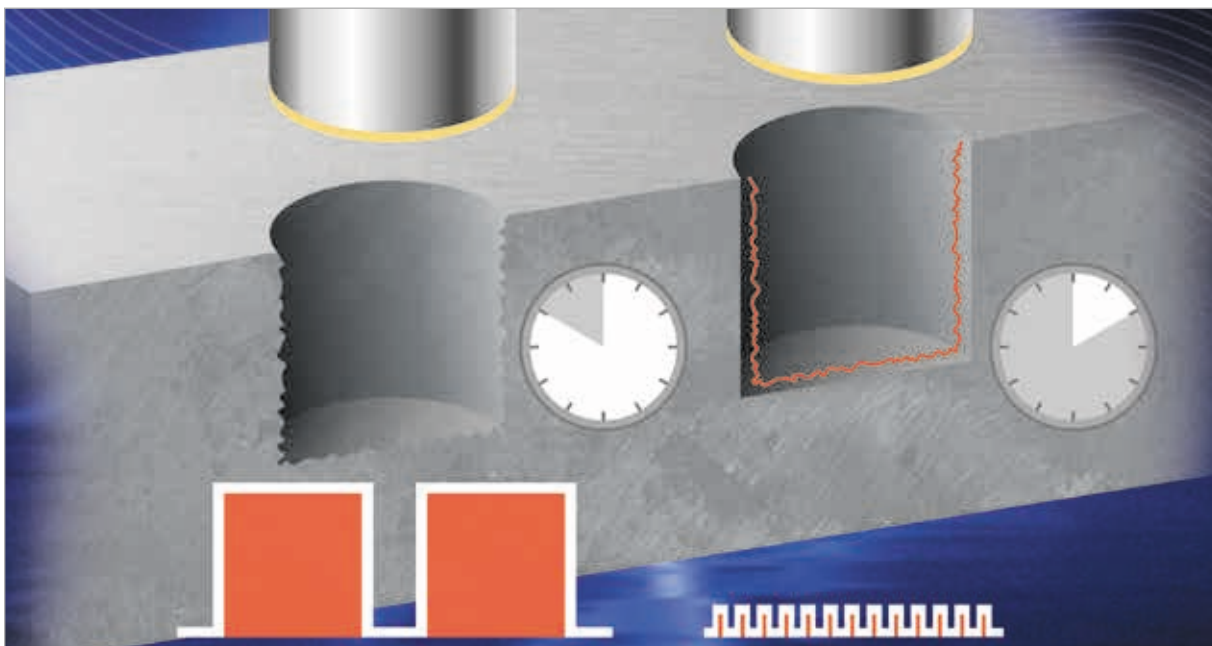lectric. Very soon it became clear, however, that liquid mineral oil derivatives had considerable advantages. Disruptive strength was greater. Smaller spark gaps could be used, making higher precision possible. Spark frequency could be increased and metal particles could be removed without difficulty. Without these mineral oil products the industrial utilization of spark erosion would never have become possible. Initially products containing petroleum and products derived from white spirit (e. g. Kristallöl 60) were used.

	Crude Petroleum	White spirit (Kristalloel 60)
Density at 15° C	0.790	0.790
Viscosity at 20° C	1.8 cSt.	2.0 cSt.
Flashpoint °C	54 – 58	60
Initial boiling point °C	180	180
Final boiling point °C	220	210
Evaporation no. (ether = 1)	220-250	295
Aromatic compounds % in vol.	17	18

From 1960 onwards the mineral oil industry began developing industrial fluids specifically for use in spark erosion machines.

3. Functions of the Dielectric

Insulation

One important function of the dielectric is to insulate the workpiece from the electrode. The disruptive discharge must take place across a spark gap which is as narrow as possible. In this way efficiency and accuracy are improved.

Ionization

As quickly as possible, optimum conditions for the production of an electrical field must be created and then a spark path must be provided. After the impulse the spark path must be deionized quickly so that the next discharge can be made. The dielectric ought to constrict the spark path as much as possible so that high energy density is achieved which increases discharge efficiency at the same time.

Cooling

The spark has a temperature of 8000–12000° C when it punctures the workpiece and so the dielectric must cool both the electrode and the workpiece. Overheating of the electrode must be avoided, so that excessively high electrode wear does not occur. It must be possible for the metal gases which develop during spark erosion to condense in the liquid.

Removal of waste particles

Metal particles that have been eroded away must be removed from the area of erosion by the dielectric to avoid disruptions in the process.

4. Requirements for Dielectrics

Theoretically all insulating liquids can be used as dielectrics. However, due to the requirements set out below, only deionized water (for polishing) and hydrocarbons are used for this purpose today. These hydrocarbons can either be produced by distillating and refining mineral oil, or synthetically by processing gases in a synthetizing oven with the help of a catalyst. Synthetically produced hydrocarbons are characterized by otherwise unparalleled purity. In addition, precisely those chains of hydrocarbon molecules can be synthetized which have the best possible erosive effect as well as offering optimum protection against electrode wear. In this way they are far superior to those mineral oil products which are produced from other mineral oil fractions.

5. Criteria for assessing Dielectrics

The following criteria are generally used today to assess different dielectric fluids:

a) Degree of metal removal and electrode wear
b) Effects on health:
   skin irritation
   toxicity
   smoke
   odours
c) Flash point
d) Density
e) Evaporation number
f) Viscosity
g) Conductivity

h) Dielectric constant
i) Disruptive
j) Particle suspension
k) Filterability
l) Compatibility with other machine components (machine parts, varnish, sealing material)
m) Aging stability
n) Constancy of quality
o) Availability
p) Price

In general it can be said that it is easy to develop a product which achieves excellent results according to one or another of the above criteria. However, it is important for the utilized product to achieve an optimum in them all, if possible. Thus it is possible for a product of the highest mechanical efficiency, combining high metal removal with low electrode wear, to be unusable in practice, because of physiological reasons, or because it eats into engine parts.

Effects on health

In the present, and certainly even more so in future, the health effects of industrially used hydrocarbon fluids are becoming increasingly important. Smoke, odours and skin irritation have a decisive influence on working conditions at spark erosion machines.

Skin irritation

Products, which are so pure that they are unharmful from a dermatological point of view should always be given preference over others. As much as possible these products ought to consist of completely saturated hydrocarbons and should contain as few aromatic compounds as can be. An aromatic content of less than 1% in vol. is desirable. Hydrocarbons from the normal paraffin series of C12 to C14 often cause skin irritation and ought not to be used. If at all possible only such products which have been proven to be unharmful to the skin by independent medical tests should be used.

Toxicity

Low aromatic content in an unused product is not on its own an indication of good quality. Far more important is the question, to what extent there is a tendency for aromatic compounds to develop during erosion (aging stability). Even after the product has been in use for some time it must not develop any polycyclic aromatics (e.g. benzpyrene), which are considered to be carcinogenic.

Smoke

The amount of smoke given off during erosion is largely dependent on the varying rates of metal removal. Thin-bodied dielectrics usually give off less smoke than more viscous ones. The higher the flow of the dielectric over the place of erosion, the less it smokes. (According to German engineering guidelines – VDI 3402 – the dielectric level must be at least 40 mm above the place of erosion.) A ventilator should always be provided at a spark erosion machine, unless it is used exclusively for fine work.

Odours

The unused dielectric should be odourless and should not begin to smell, even when heated. After it has been used for some time, it is normal for a faint ozonic smell, caused by the electrical discharges, to develop. A sour, acrid smell is often an indication that the dielectric ought to be renewed.

Flash point

The flash point is the lowest temperature at which a dielectric gives off sufficient vapours to produce an inflammable mixture of air and gases in a standardized apparatus. The higher the flash point, the safer is the use of the dielectric. Dielectrics are divided into different danger classes according to their differing flash points.

Danger class: A I   under 21° C,   e. g. benzine
                 A II   21 – 55° C,   e. g. crude petroleum, white spirit
                 A III   55 –100° C,   e. g. diesel, light fuel oil

The VbF (Regulation on Flammable Liquids) was replaced in Germany by the Industrial Safety Regulation on October 2nd, 2002, but is mentioned here as the VbF classifications are still widely known and used. According to German engineering guidelines – VDI 3402 – substances with flash points below 21° C may not be used in spark erosion machines. It must also be pointed out that crude petroleum and white spirit are in danger class A II and that special safety regulations must therefore be complied with when they are used. Most of the dielectrics in use today are in danger class A III. Dielectrics whose flash point is over 100° C are not considered to be inflammable as defined by German law. No special safety measures are therefore needed for them. To determine the flash point of fluids in accordance with the German legal provisions for industrial substances, flash points up to 50° C must be measured with the Abel-Pensky apparatus, while flash points of over 50° C must be measured with the Pensky-Martens apparatus (Flp. PM). It is not permissible to use an open cup apparatus, such as the one developed by Cleveland.

Density (German standard – DIN 51757)

Irrespective of viscosity, the influence of density is greater during the finishing process than in rough cut operations. „Heavy" products remove more metal. The density of a substance is the ratio of its mass to its volume (usually measured at a temperature of 15° C). Dielectrics normally used today have a density of 0.750–0.820. The shorter the chain of hydrocarbon molecules, the lower its specific gravity. Changes in the specific gravity of a dielectric before and after use indicate that alien substances, such as hydraulic fluid, have entered it. Density increases in a dielectric which was blended from different fractions show to what extent the more volatile parts have evaporated. Density can easily be checked with a densimeter (hydrometer). This is a floating glass instrument with a density scale (units of 0.001) also containing a thermometer.

Evaporation number (German standard – DIN 53170):

The evaporation number (VD) is the ratio of evaporating time for the dielectric to that for ether. Dielectrics for polishing work should have an evaporation number of 500–1000. For economic reasons, substances that evaporate more quickly (e. g. Petroleum VD 260) are not suitable as dielectrics.

Viscosity (German standrad – DIN 53170):

Viscosity is the property of a fluid whereby it tends to resist the displacement of two neighbouring layers. The physical unit of measurement of absolute viscosity is the Pascal second. One mPa.s is equal to one Centipoise (cP). The ratio of absolute viscosity to density is called kinematic viscosity. The unit of measurement is the square metre per second (M^2/s). A centistoke (cSt) is equal to 1 mm^2/s. The viscosity of thin-bodied dielectrics is usually measured at a temperature of 20° C. Dielectrics of 2 to 3.5 cSt at a temperature of 20° C are suitable for polishing work. 4 to 6.5 cSt at 20° C is suitable for rough cut operations. The disadvantage of dielectrics which have been produced from two fractions of differing viscosity is that the more volatile, less viscous components evaporate more quickly, leaving behind a dielectric which is so viscous after prolonged use that it is suitable only for rough cut operations. The surface roughness of the processed workpiece is also dependent on viscosity. Thus a narrow spark gap can be used with a thin-bodied dielectric, leading to a finer finish. When more viscous dielectrics are used, a larger spark gap must be chosen to avoid flushing difficulties. This leads to greater roughness in the processed workpiece (see Figure 1).

Table of recommended viscositz as a function of R_{max}
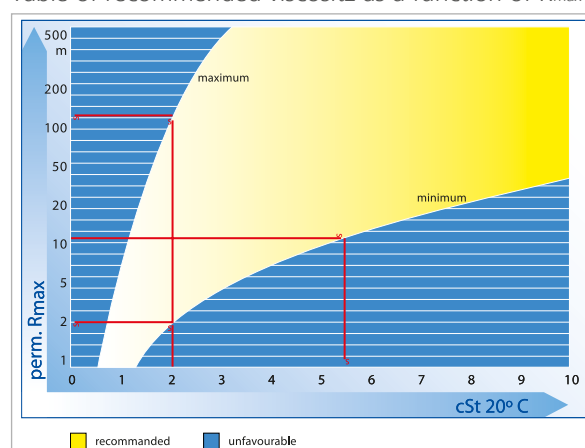

Figure 1

Conductivity

Conductivity is equal to the reciprocal of volume resistivity. The unit is the Siemens. A conductivity AC bridge on the Whetstone bridge principle, at frequencies of 50 or 3000 Hz, is used for measurement. Hydrocarbon dielectrics for industrial use have a conductivity of about $2x10^{-14}$ ohm x cm^{-1} when new.

Dielectric constant (German standard DIN 53483)

The relative dielectric constant (DK) of a particular dielectric shows to what extent the capacitance of an empty capacitor is increased by introducing that dielectric. A (dielectric constant) DK-meter is used to measure the dielectric constant. The capacity of a capacitor is measured by connecting it to a high frequency resonant circuit, both when filled with dielectric and when empty. The dielectric constant is the ratio of the two different values obtained. A dielectric suitable for spark erosion ought to have a dielectric constant of 2–2.5.

Current

Depending on the oelheld dielectric used, currents of up to 1,200 Ampere can be realized.

Disruptive voltage (German standard – DIN 53483; German electrical guidelines – VDE 0303)

The voltage required to disrupt a 2.5 mm layer of dielectric between two spherical electrodes is called disruptive voltage. Good dielectrics should have a disruptive voltage of 50–60 kv when new. It must be noted that the least amount of moisture added to the dielectric (e. g. condensation water) will have a negative influence on this value.

Particle suspension

Waste particles eroded away from the workpiece and the electrode, as well as carbon particles resulting from electrical discharges, are impurities in the working substance. The dielectric must remove these particles from the work area. Adequate particle suspension is necessary for this task. However, particle suspension must not be too high, otherwise these impurities will not separate from the Dielectric during filtration. Too many impurities lead to arcing. On the other hand, a dielectric will only function in the best possible way if a few micro-particles are to be found in the dielectric, as this is conducive to ionization. These tiny particles can even be added to the dielectric artificially when it is new to improve erosion from the start.

Compatibility with other machine components

Dielectric fluids in industrial use must remain neutral towards other machine components with which they come into contact, e.g. sealing material, tubes and varnish used in containers. The dielectric must not cause these materials to swell up, shrink or dissolve.

Aging stability

Aging stability in dielectrics is very important for economic reasons. The longer a product can be used, the better is the relationship of price to performance. With normal erosion operation, the dielectric can be used for a long time with ideal filtration. When used in microfilter systems, operating times of up to 25 years are already common today, without the dielectric having to be replaced.

In these cases nothing more was done than to replenish the dielectric tank as the need arose. Age can be assessed by means of infrared spectrographic analysis, but the alternative method, by which neutralization value is determined (NZ/German standard DIN 52558), has also proved to be reliable up to the present. Dielectrics with an acid number of more tha 1 mg/KOH/g ought to be renewed as soon as possible.

Quality and availability

The producer of a dielectric must be able to guarantee its quality for an adequate period of time. In addition, the quality of a dielectric sold under the same name in different countries must always be the same. Dielectric fluids for industrial use ought to be available in those quantities, in those localities, and within those time periods, in which they are required.

Prices

When prices are compared, all the above criteria must be taken into consideration, as the dielectric which is cheapest at first is often the most expensive in the long run.

6. The flushing process during spark erosion

Every experienced spark erosion expert knows that the flushing process is of utmost importance when metals are subjected to this procedure. The dielectric must flush away the eroded particles from the gap between electrode and work piece, otherwise they may form bridges, which cause short circuits. Such arcs can burn big holes in the work piece and in the electrode. Modern spark erosion plants therefore have a built in power adaptive control system, which increases pulse spacing as soon as this happens and reduces or shuts off the power supply completely. The more thin-bodied a dielectric and the lower its surface tension, the better it is able to meet flushing requirements.

Open flushing

Open flushing is the most common form of flushing and is used when it is impossible to flush through the electrode or workpiece.
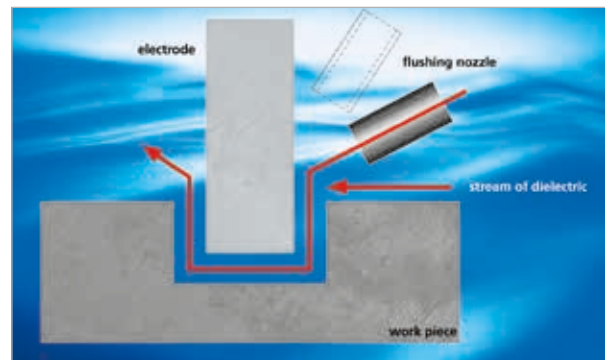

Figure 1: Open flushing

Pressure flushing

Next to open flushing, pressure flushing is the most important form. The dielectric is either pushed through a flushing hole in the electrode from above, or through a flushing hole in the work piece from below. The amount of dielectric flowing through is more important than the pressure of flushing.
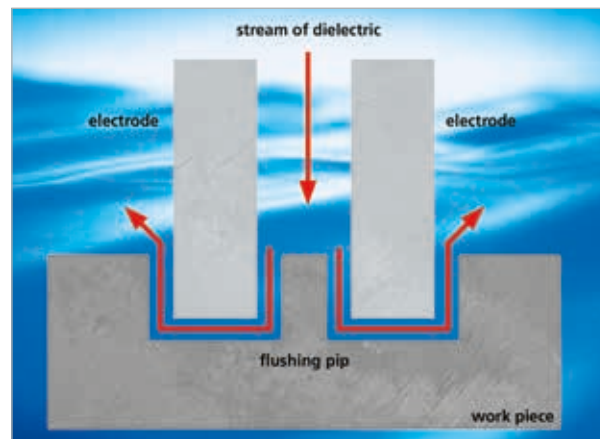

Figure 2: Pressure flushing

When calculating the smaller than specified dimension of the electrode, it must be remembered that in this type of flushing particles rising up through the lateral gap are continuously causing additional erosion. This leads to minor defects in precision, sometimes called secondary erosion.

Figure 3: Pressure flushing

Suction flushing

In suction flushing the eroded particles are sucked out of the gap between electrode and work piece. This type of flushing is best in those cases, where a fine finish and parallel walls are required in the work piece. When using this method with narrow gaps and small amounts of dielectric flowing through, care must be taken that enough dielectric gets into the spark gap, so that the spark erosion process will remain stable.

Figure 4: Suction flushing

Combined flushing

In very complex jobs it may be advisable to combine suction and pressure flushing.

Figure 5: Combined flushing

Interval flushing

In interval flushing the erosion process is interrupted after a while and the electrode is retracted. This improves the flushing out of the eroded particles. The retraction and return of the electrode has the additional effect of suction and pumping respectively, which improves the effectivity of the flushing process. This method is particularly suitable, when deep depressions or thin electrodes are involved, and also during finishing work.

7. Filtering the Dielectric

In order for the dielectric to perform its flushing function in the best possible way, eroded particles from the workpiece and the electrode, as well as the cracked parts of the dielectric itself, must be removed. In addition the dielectric, which heats up during spark erosion, has to be cooled down again to a normal working temperature of 20° C– 30° C. If it is too hot, there will be inaccuracies in the work and much of the dielectric will be lost through evaporation. For this reason every spark erosion machine has a filtering plant, which has the following functions to perform:

a) Storing the dielectric
b) Cleaning the dirty dielectric coming from the work tank
c) Providing the required amount of clean fluid and the necessary pressure for rapid filling as well as for pressure and suction flushing

d) Cooling the dielectric (by air, water or cooling plant)
e) Processing backwashed fluid and filtrate

23
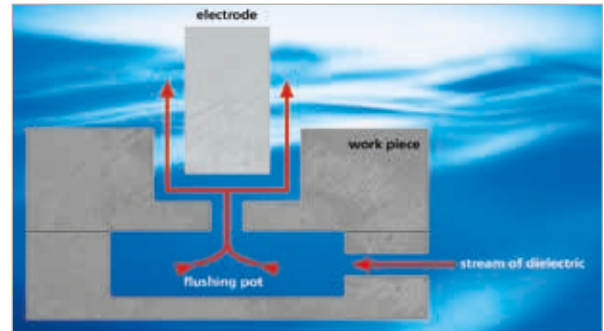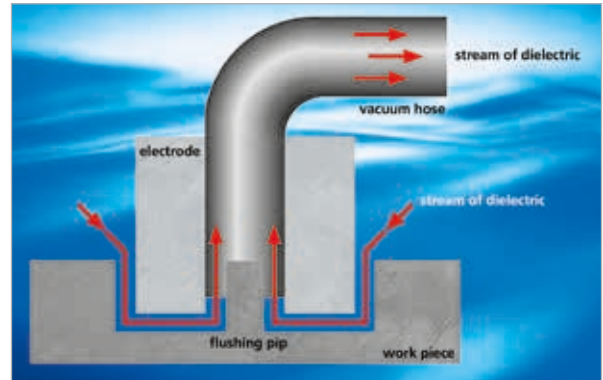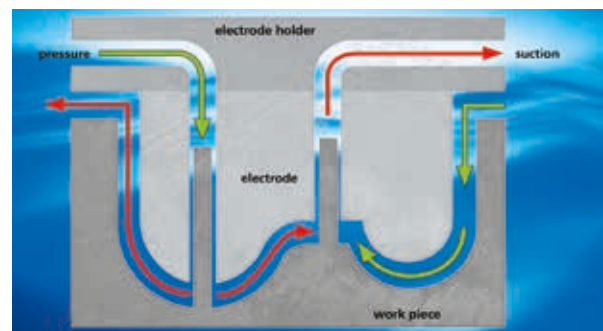
Cartridge filter system (see Figure 1)

In practice cartridge filter systems have proved very effective for filtering dielectric in smaller spark erosion plants, in which up to approx. 450 mm2/min are eroded. Cartridge filter systems are simple, and, as far as the cost of acquisition is concerned, inexpensive apparatuses. In the main they consist of a storage tank, filter pump, machine pump, cartridge filter, cooler and the requisite piping. The plant is operated manually. The filter element itself is housed in a pressure resistant container and consists of a piece of paper, folded like a star and arranged around a central pipe. The filter cartridge is not reusable. Once it has attained its maximum capacity for retaining dirt, it has to be replaced by a new one. The fineness of the filtering effect of such a plant lies between 1 and 5 µm, depending on the paper used. Under normal conditions the dielectric IME can be used with a paper filter plant for about 1–2 years.
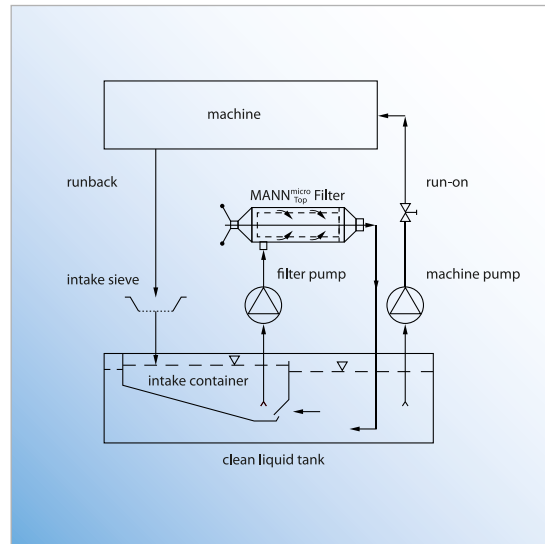

Figure 1

Precoated filter system (see Figure 2)

In big spark erosion plants it is advisable to mount a so called precoated filter system. In these systems the filter elements are coated with an even layer of filter aid, before filtering begins. This layer may consist of diatomite, Rixid or cellulose. After precoating is completed, the filter cycle of the plant is started, either by hand or by machine. After a maximum differential pressure has been reached, the entire filter system is flushed back and all the dirt on the filter elements, plus the filter aid, are expelled via a mud valve into the after-filter. After the flushing back process is completed, the filter plant can be precoated anew and the filter cycle restarted. The filter area should be large enough, so that all the dirt accumulating during one shift can be absorbed, before flushing back becomes necessary. A fineness of up to 1 µm can be achieved with precoated filter systems. On the average 1 kg of diatomite or 0.5 kg Rixid are required for 1 m2 filtering area. The residual moisture of a dry sludge cake discharged from a precoated filter system lies between about 20 % and 30 % of the weight, depending on the type of dielectric used.
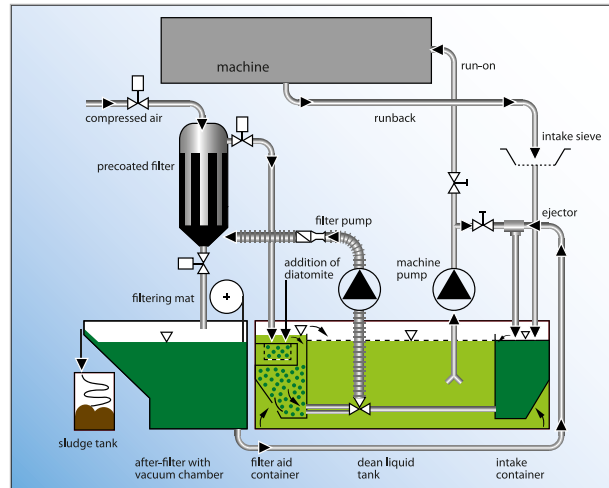

Figure 2

The service life of the dielectric in precoated filter systems is very long, since diatomite and Rixid not only have a mechanical cleaning effect, but also filter out acid components from the dielectric to a certain extent. In precoated filter systems bleached earth may also be used as a filter aid, in order to clean the dielectric even more thoroughly. There is data available from precoated filter systems, which were filled twenty years ago with a quantity of the dielectric IME, which is still fully operative today. Only the amounts lost through drag-out and evaporation had to be replaced.

The Transor filter system (see Figure 3)

The Transor filter system is able to produce a filtering effect of 1 μm without the use of filter aids by employing the edge filter principle. Filtering rods, on which thousands of extremely fine special paper discs are mounted, are installed in a pressure tank. The dirty dielectric is pumped into the pressure tank and pressed through the filtering rods from the outside to the inside. As this system works without filter aids, no pre-coating is necessary. The gaps between the paper discs are so narrow, that all particles that are larger than 1 μm are deposited on the surface of the filter rods. When the rods are dirty, backflushing occurs, and the dielectric, which has already been filtered, is pressed back through the filter rods in the opposite direction. The dirt layer on the filter rods is blasted off and can be taken out of a sludge tank. There is little sludge in comparison to the precoated filter system, because no filter aids are used. The service life of the filter rods is on the average about 8,000 working hours. In a Transor filter system one must make sure that the viscosity of the dielectric does not excede 4.0 cSt at 20° C.

Diagram of a filter system for dielectrics working according to the edge filter principle

a) filter container
b) filter rods
c) filter pump
d) sludge tank
e) clean oil tank
f) clean oil tank
g) machine pump
h) oil air cooler
i) water trap and reducing valve for compressed air
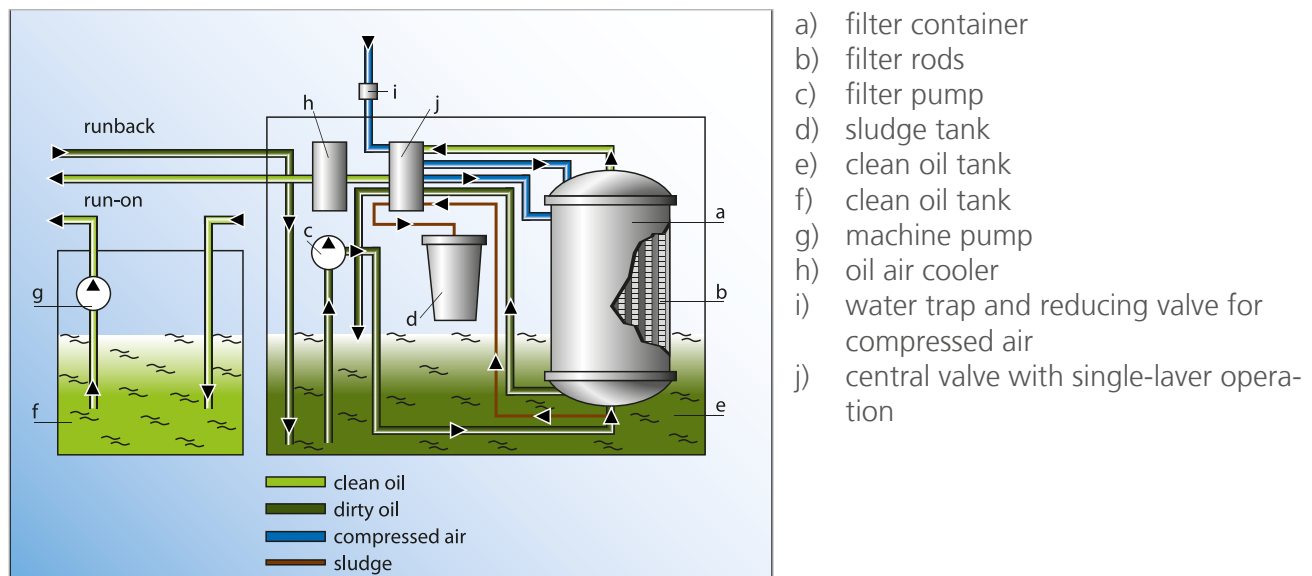j) central valve with single-laver operation

Figure 3

8. The effect of spark erosion on the work piece

Spark erosion has a completely different effect on working material than customary methods of processing. The electrical spark hitting the work piece heats up the outer layer of the steel so much (about 10,000° C) that the material evaporates. The metal gases formed then condense in the dielectric, usually in the form of hollow balls, open on one side and having a sharp edge. In the work piece itself depressions, shaped like craters, are formed. How great is the danger for the working material to be so unfavourably affected on the surface, that the serviceability of the tool suffers? And what about tool life, resistance to wear and buffability? Figures 1, 2 and 3 show surface roughness, electrode wear and metal removal in relation to the firing period.
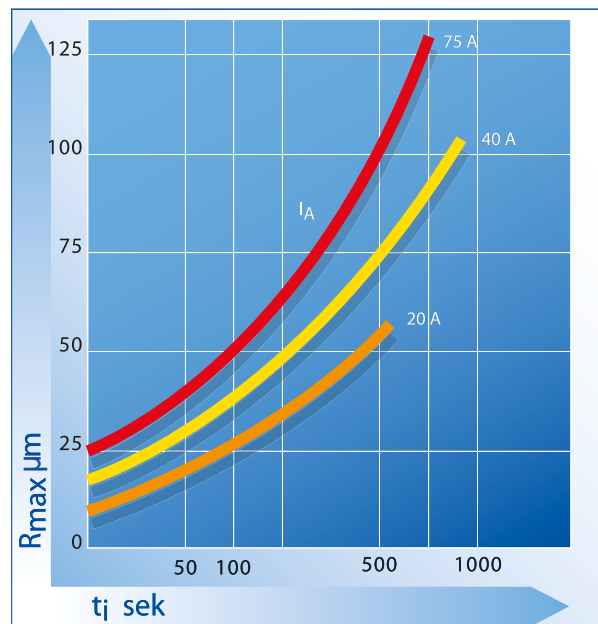

Figure 1:
Surface roughness in relation to firing period
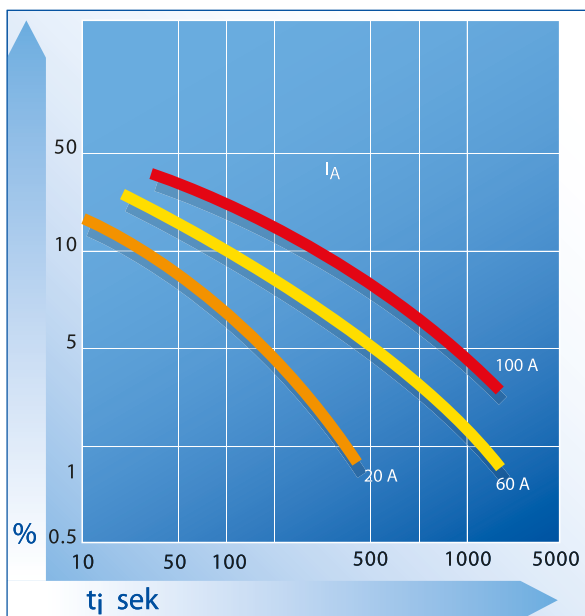
Electrode wear relative value

Figure 2:
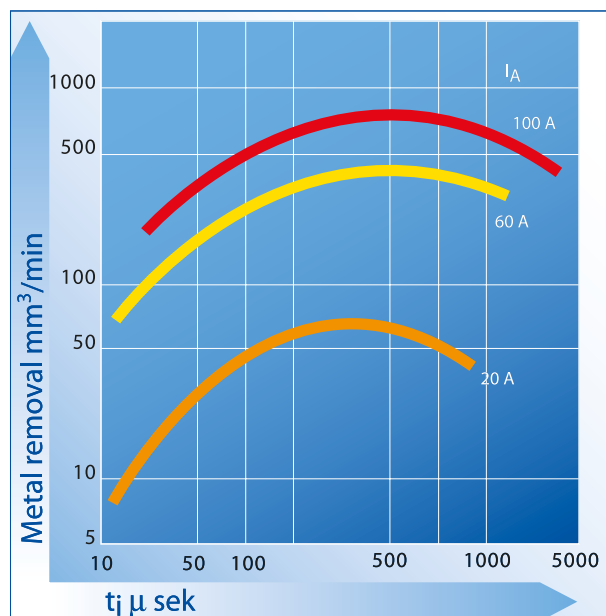Electrode wear in relation to firing period

Figure 3.
Metal removal in relation to firing period

Apart from metal removal, surface roughness and electrode wear, the effect on the surface quality of the working material is of utmost importance. In most cases it was shown that there was no effect on the functioning of the tool. In some cases, e.g. in a cutting tool, it even became more resistant to wear, in others, however, tools broke prematurely. All changes that could be detected were due to the high temperatures that were produced on the rim. In this rim the structure, hardness, state of stresses and carbon content of the steel are influenced. Figure 4 shows a section of a surface that has been roughened down by spark erosion, showing the various structural changes, which are typical of such a rim.
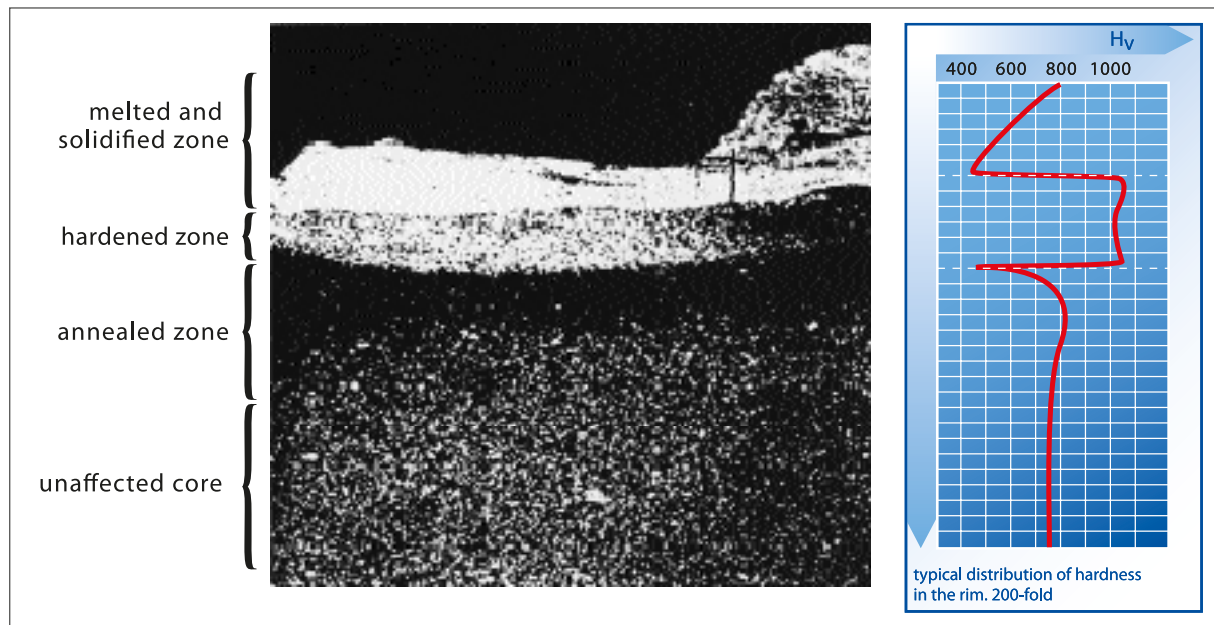

Figure 4:
Section of a surface that has been subjected to spark erosion with structural changes Material: UHB Rigor, hardened to 57 HRC

The **melted zone** (Figure 5) shows clearly that it has solidified very quickly. Columnated crystals have grown vertically up out of the metal surface during solidification. A crack that has formed in this layer runs inward along the line of crystals.

The **melted layer** is usually about 15–30 μm thick after normal rough work. In the hardened zone the temperature rose above that needed for hardening. A hard and brittle martensite has formed.

In the **annealed zone** the temperature was not so high as to harden the steel. It has only been tempered. Underneath is the unaffected core. The thickness of the various layers appears to be unrelated to the type of steel used and the electrode material. However, there is a very clear difference between hardened and softened materials. In softened steel the layers are thinner and there are fewer cracks. The brittle, hardened layer is almost non-existent. During rough work the thickness of the layers varies much more than during finishing. The longer the firing period, the thicker the melted and hardened layers become. Further research has shown that the strength of current has basically the same effect as the length of the firing period. Steel with a high carbon content gets the most cracks. Steel with a low carbon content develops fewer cracks in the melted layer. About 20% of the cracks extend into the hardened zone and only a few reach the core. In the core there are seldom cracks longer than 10 μm. These cracks in the core are usually found in high alloy tool steel and in high alloy high-speed steel.
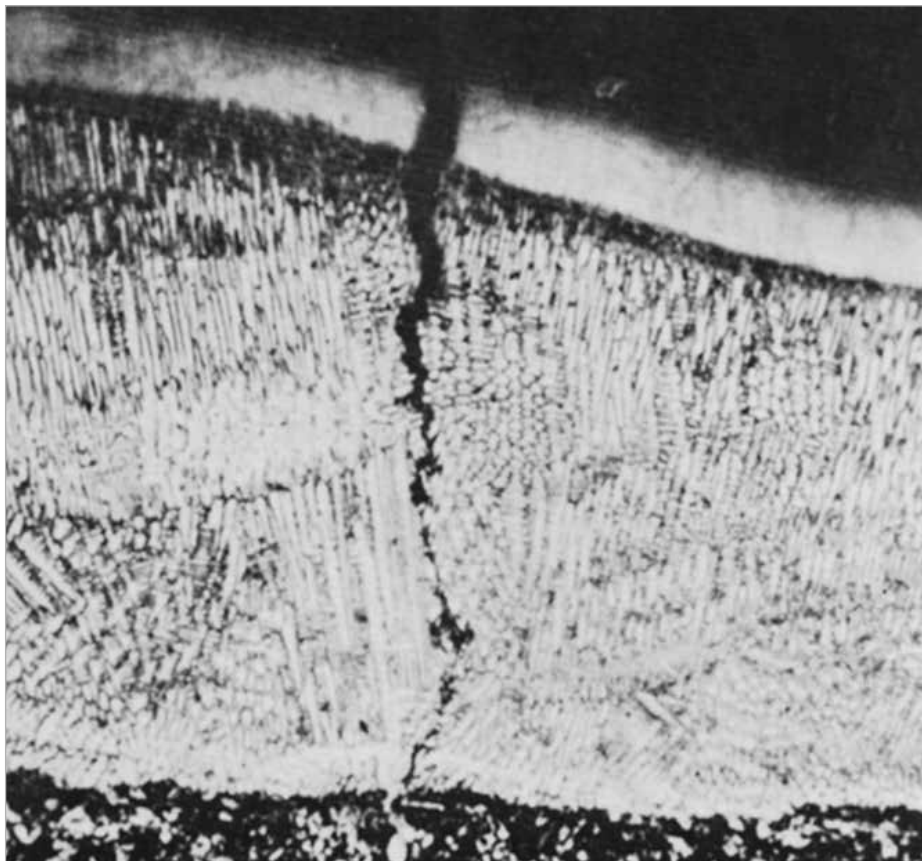

Figure 5

Figure 6a (top left) — Cu-electrode, hardened

thickness µm — axis: 100, 80, 60, 40, 20, 0

Labels: Cu-electrode, melted zone, hardened zone, core

t_i sek	10	200	500	1000
[1]	–	12	29	43
[2]	–	–	2	2
[3]	–	–	1	1

Figure 6b (top right) — Cu-electrode, annealed

thickness µm — axis: 100, 80, 60, 40, 20, 0

Labels: Cu-electrode, melted zone, hardened zone, core

t_i sek	10	200	500	1000
[1]	2	1	8	9
[2]	–	–	–	–
[3]	–	–	–	–

(bottom left) — graphite elektrode

thickness µm — axis: 100, 80, 60, 40, 20, 0

Labels: graphite elektrode, melted zone, hardened zone, core

t_i sek	100	200	500
[1]	21	25	43
[2]	–	–	3
[3]	–	–	–

(bottom right) — graphite electrode

thickness µm — axis: 100, 80, 60, 40, 20, 0

Labels: graphite electrode, melted zone, hardened zone, core

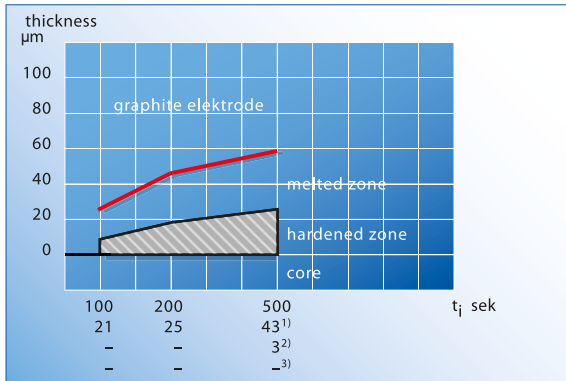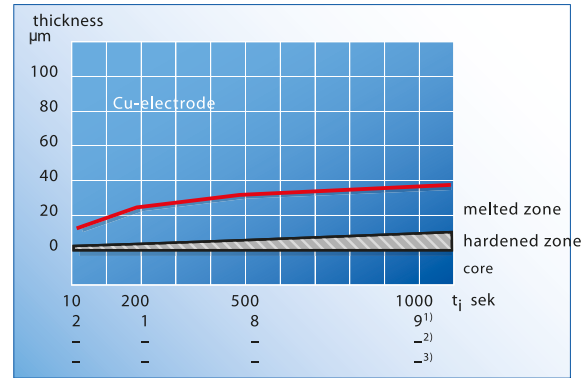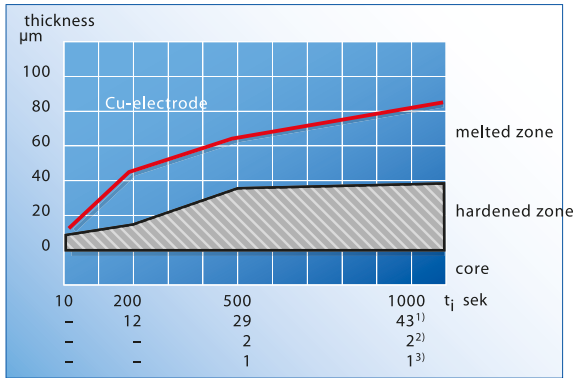| t_i sek	100	200	500	1000
[1]	5	19	15	
[2]	–	–	–	
[3]	–	–	–	

Figure 6a:
Thickness of layers and amount of cracks in the rim after spark erosion on hardened (52 HRC) UHB Ovrar 2 microdized at different lengths of firing period
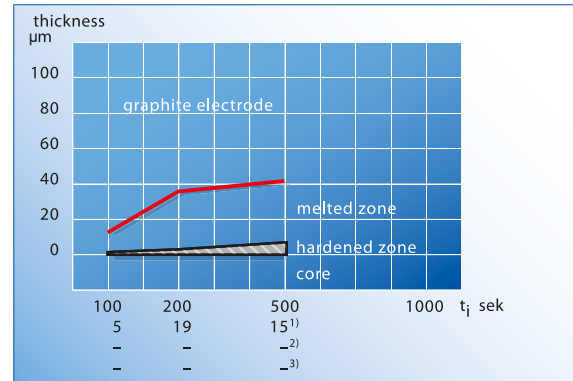
Figure 6b:
The same after spark erosion on UHB Ovrar 2 microdized which has been annealed

Number of cracks/cm
1) (in the melted zone)
2) (in the hardened zone)
3) (in the core)

The cracks are caused by stresses which result from the repeated rapid chilling of the work material by the dielectric, as well as from the differences in volume between the various structural parts in the different layers. If erosion is properly done and includes the final finishing process, the surface errors that result from rough work can largely be corrected. Where finishing is not possible, the following procedures may be used:

a)   **stressfree annealing** at about 15° C less than before. This decreases the hardness of the surface without influencing the core.

b)   **softening** and renewed hardening and annealing leads to an almost complete restoration of the structure (cracks however remain)

c)   **grinding** or **scouring** removes the surface structure together with the cracks. The rate of cut is important here, and should be about 5–10 µm.

In summary it may be said that the structural faults caused by rough work can be corrected during the normal process of spark erosion, which includes rough work and finishing. A certain amount of structural changes will, of course, always remain. However, in most cases they are of little importance. There are even instances in which the great hardness of the hardened layer improves the tool's resistance to wear. In others, the craters on the surface of the work piece provide a better hold for lubricants, which also increases the service life of the tool.

9. IonoPlus® – a new way to better dielectrics

Every experienced operator of spark erosion machines is acquainted with the phenomen that better results are obtained with a used dielectric than when it has just been renewed. The reason for this is that finely dispersed waste particles make it possible for ionisation channels to build up more rapidly. In tests a fresh dielectric is always put to use for at least half an hour before the actual test phase is begun. Many years ago our firm also conducted experiments using dielectrics to which metal pigments or organometals had been added. It was intended to induce a „controlled" effect of increased metal removal. Unfortunately most of these additives settled on the bottom of the work tanks even when their specific gravity was very low (e. g. with powdered aluminium) - or were taken up the filters. Only after these microparticles had been reduced in size even further, was there a real improvement in metal removal.

The starting point for the development of dielectric IonoPlus® IME-MH was the idea of formulating a dielectric that could be used for rough cut as well as finishing and polishing processes. In addition it was intended that it should increase metal removal and decrease electrode wear. From a physiological point of view the new dielectric was to be safer as well, so that it would no longer fall under danger class A III for inflammable liquids. Of course it also had to work with all conventional filter systems and had to be simple to dispose of.

This goal has been reached by using substances floating in the dielectric that turn into stronger dipoles than the surrounding hydrocarbons when they come under the influence of an electrical field. On application of an electrical current, these chemical satellite electrodes align themselves along the lines of electric flux in the electrical field and channels of increased electrical conducting capacity develop in the dielectric liquid. In this way the discharge channels required for spark disruption can build up more rapidly than usual. This in turn leads to a steeper increase in ignition voltage and faster spark disruption. Thus the amount of metal removal per unit of time is significantly increased.

In contrast to conventional dielectric liquids the dielectric IonoPlus® IME-MH does not induce a direct flow of electrons from cathode to anode.
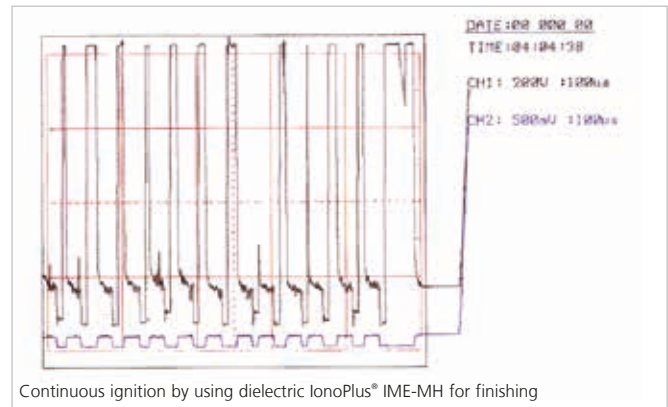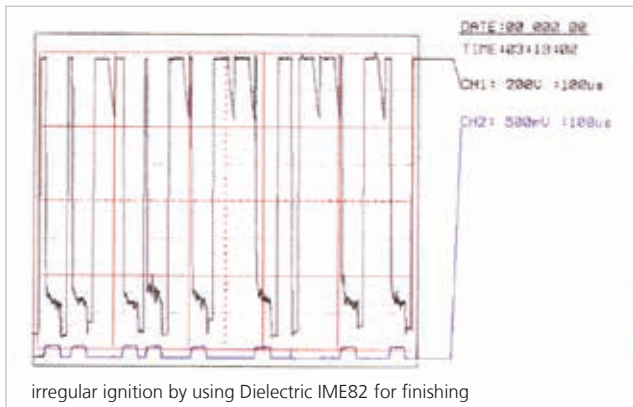Most of the electrons are attracted by the finely distributed satellite electrodes and conducted along a widely ramified network of channels. Since they lost part of their kinetic energy in the process, they hit the anode with relatively little energy. A decrease in ignition time delay is achieved at the same time, because of the steep increase in ignition voltage. Both of these effects lead to a decrease in anode wear. In comparison electrode wear is reduced by up to 30%.

In spark erosion for finishing purposes (with reversed polarity) the work piece serves as anode. Again the satellite electrodes dampen the impact of the electrons which now hit the work piece with less kinetic energy and are more widely distributed than when a conventional dielectric is used. The satellite electrodes lead to a faster build-up of the ionisation channel and thus make it possible for less average current to be applied in processing the work piece.

By means of this new technique, very well polished workpiece surfaces with a surface roughness of less than 0.1 µm can be produced. This polishing performance, i. r. o. surface quality and speed cannot be achieved with conventional dielectric fluids.

The use of highly polarized substances in IonoPlus® IME-MH also has a very positive effect on its dispersing qualities. The waste particles produced by the spark erosion process are hurled explosively out of the work area in the finest distribution. This reduces the tendency for short circuiting and leads to an undisturbed process in spark erosion. The reason for these good dispersing qualities are the electrical dipoles aligned in the satellite electrodes, leading to a quicker distribution of the waste particles due to their electrical repulsion forces.

Technical data of IonoPlus® IME-MH:	
Danger class VbF:	none
Transportation class:	none
Tank truck marking:	none
Danger number:	none
Substance number:	none
GGVSee IMDG-Code:	none
IATA-RAR	
article no.	none
class	none

irregular ignition by using Dielectric IME82 for finishing

Continuous ignition by using dielectric IonoPlus® IME-MH for finishing

Powerful advantages for spark erosion:

## The first dielectric with the plus of satellite electrodes

After many years of research oelheld introduces an entirely new, powerful concept into dielectrics: **IonoPlus® IME-MH**. Unlike conventional mineral oil products, this combination of highly refined synthetic products is enriched with satellite electrodes in a special blending process. As a truly universal dielectric, **IonoPlus® IME-MH** is suited for all operations from the finest finishing processes to the most effective rough cut. Besides having the best possible effectiveness in flushing and the greatest possible disruptive strength, it offers a whole series of unique advantages.

IonoPlus® IME-MH dielectric can be used in all conventional filter systems. **IonoPlus® IME-MH** dielectric is not regulated by the Industrial Safety Regulation.

Advantages

- **Greater efficiency in metal removal**
  The time needed to build an ionization bridge is substantially reduced.

- **Greater resistance to electrode wear**
  Macromolecules surround the electrode like a protective grid.

- **Improved surface quality**
  Satellite electrodes bring about an optimal distribution of discharges.

- **Shining results in the polishing process**
  Within a minimum amount of time a surface roughness of less than 0.1 µm can be achieved.

- **Best possible dispersing capacity**
  wift dispersion of waste particles helps actively to prevent burn spots from forming.

Technical Data:		
Colour	flourescent green	
Density at 15 °C (g/cm³)	0,79	DIN 51757
Viscosity at +40 °C (mm²/s)	2,50	DIN 51562
Pourpoint °C	-15	DIN ISO 3016
Flashpoint °C	107	DIN EN 2719
Aromatic content (weight%)	0,01	DIN 51378
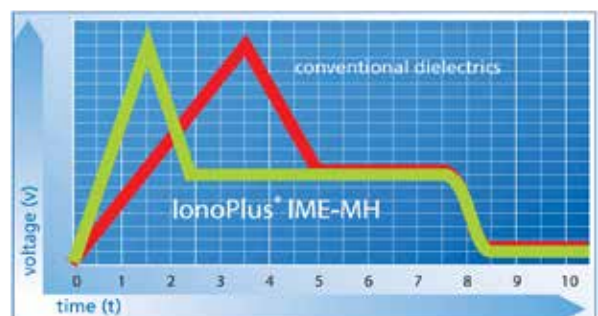
10. Dielectrics IME 63, IME 82, IME 110, IME 126

IME dielectrics are synthetic products manufactured in a catalytic process and posessing great disruptive strength. They are clear fluids and are almost odourless. They do not change colour during erosion. They have the same purity as pharmaceutical white oil.

IME dielectrics have been subjected to extensive tests and have proven themselves in practice for decades. They are explicitly recommended by the leading manufacturers of spark erosion machines. Whether in rough cut operations or in fine work – the dielectric must meet the specific requirements of each particular case of application. The high-performance dielectrics for use in electrical discharge machining are produced on a synthetic base and have additives with aging inhibitors.

DIELECTRIC IME 63
Dielectric IME 63 is an extremely thin-bodied dielectric with the least possible surface tension. It is particularly suitable for very fine work when a very low overcut is required, e.g. the microboring of spinnerets and the manufacture of microelectronic parts.

DIELECTRIC IME 82
Dielectric IME 82 combines high metal removal with low electrode wear which makes it suitable for general use in manufacturing tools and moulds. Even rough cut operations using an electric current of 600 amps can be carried out with IME 82.

DIELECTRIC IME 110
Dielectric IME 110 is always used when a flash point of over 100° C is required while much finishing work also has to be done. Dielectric IME 110 lies outside danger class A III.

DIELECTRIC IME 126
Dielectric IME 126 is a dielectric for very high metal removal in rough cut operations such as in the manufacture of forging dies. It can only be used for finishing if the best possible flushing conditions are ensured.

Technical data on the dielectrics	IME 63	IME 82	IME 110	IME 126
Colour	clear	clear	clear	clear
Density at 15 °C g/ml	0.765	0.789	0.775	0.824
Viscosity cSt. at 20 °c	1.8	3.0	3.4	5.8
Flash point °C (PM)	63	82	106	114
Pourpoint °C	-40	-40	-6	-5
Aromatic content % weight	0.003	0.02	0.01	0.1
Disruptive voltage kv at 2.5 mm	58	59	57	52
Danger class VbF	A III	A III	none	none
Transportation class VbF				
Road ADR/GGVS and	none	none	none	none
rail RID/GGVE	none	none	none	none
Tank truck marking				
Danger number	none	none	none	none
Substance number	none	none	none	none
GGVSee IMDG-code	none	none	none	none
IATA-RAR				
article no.	none	none	none	none
Class	none	none	none	none

Testing the various IME dielectrics

IME dielectrics have been tested in practice both for metal removal and for electrode wear. The following materials and operational steps were selected for these tests:

a) Materials

Electrode	**Workpiece**
1) electrolyte copper	tool steel X 210 Cr 12
2) graphite (Ellor 9)	tool steel X 210 Cr 12

b) Operational steps

	Rough cut	**Finish**
roughness H max. approx. (µm)	60	10
working time (min.)	15	60
electrode shape round ø (mm)	35	25
no-load running voltage (v)	100	100
average voltage (v)	28	28-30
average current (amp)	36	6
pulse duration (µsec)	200	10
pulse spacing (µsec)	12	2,6
flushing hole ø (mm)	7	5

V_w (mm³/min) = metal removal

ϑ % = electrode wear expressed as a ratio (in percent) of the volume of electrode material lost, to metal removed from the workpiece.

The control settings given represent easy to manage operational steps involving no special difficulties. Metal removal and electrode wear were determined by measuring weight differences which were then converted into units of volume.

Rough cut

When working with copper and steel, metal removal was lowest for IME 63 during rough cut operations, and highest for IME 126. Electrode wear was least for IME 63 and most for IME 126 (see figure 1). When working with graphite/steel similar results were obtained. Metal removal was highest for IME 126 and least for IME 63. It was astonishing that no measurable electrode wear took place when IME 110 was used.

Roughening n 12 Tr./200 µsek
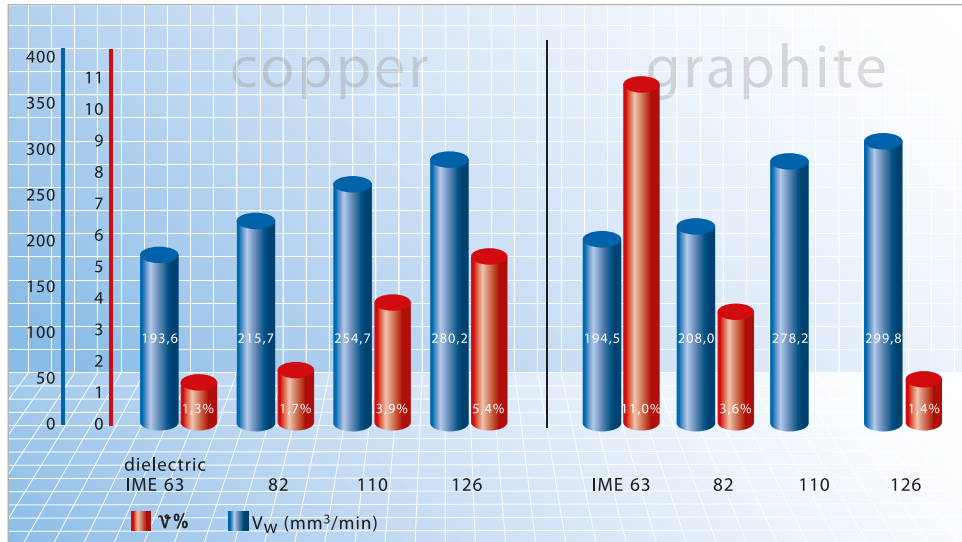
Figure 1

Finish

When working with copper and steel in the finishing process, IME 126 achieved the highest metal removal. Least electrode wear took place when IME 63 was used (see fig 2). When working with graphite and steel, IME 126 also achieved highest metal removal. The results of IME 82 were only slightly lower.

Finishing n 2 Tr./10 µsek
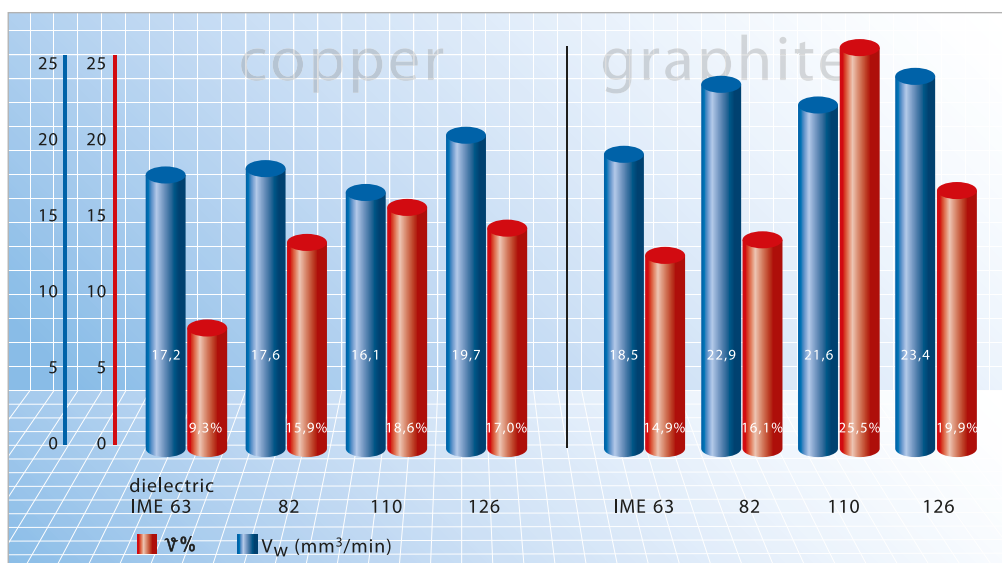
Figure 2

All these test results are valid only for the given control settings and materials. They are intended to show the varying influence of the dielectric used on the work process. The excellent results of IME 126 during finishing can undoubtedly not be achieved unless flushing conditions are optimal.

11. Gases produced during spark erosion

The gases produced during erosion consist of dielectric vapours and metallic fumes. Special attention should be paid to the resulting metal vapors (e.g. tungsten carbide, titanium carbide, chromium, nickel, molybdenum). It is therefore important for the dielectric level to be as high as possible over the place of erosion so that most of the metallic fumes and dielectric vapors can condense in the dielectric. German engineering guidelines (VDI 3402) prescribe a depth of 40 mm over the place of erosion. However, a depth of at least 50 mm is recommended for health reasons. The metallic fumes rising up out of the dielectric cause the same problems as those that develop during the welding of metals. It is therefore advisable to extract the gases that develop when extensive rough cut work has to be done.

12. Dielectrics and the human skin

Practically only one's hands come into direct contact with the dielectric during work. Remnants that are left on the skin can be removed without the use of cleaning agents that have mechanically or chemically aggressive properties. In this way secondary damage is also avoided. It is difficult to make general predictions on the effect of dielectrics on persons with particularly sensitive skin or with a tendency to allergies. However, metal particles suspended in the impure dielectric do have a negative effect on skin. These particles are microscopically small, hollow, metal beads that are open on one side and with very sharp edges. These globules can easily hurt the epidermis and lead to skin damage. Skin sensitivity can also be caused by cleaning agents and medicines. In all these cases it is advisable for a skin protecting cream that is not oil soluble to be rubbed into the hands. Skin problems can be avoided by using skin protection lotions and oil-resistant protective gloves. See skin protection plan on our oelheld homepage. Pieces of clothing soaked with dielectric should be changed at once.

13. „7 Golden Rules" for working with IME Dielectrics

Correct handling of dielectrics begins with the proper storage of packing drums:

1. If the drums are stored outdoors, they should always lie down and never stand upright, so that no rain water can seep in.

2. When the dielectric is filled into the machine, clean pumps or containers must be used. Pumps that have been used for acid or caustic solutions destroy the best dielectric instantly. PVC tubes are not oil resistant and will become rigid after they have been used for some time.

3. Anticorrosive agents, used to protect the machine during transport, must be removed before the dielectric is filled in.

4. Chlorinated hydrocarbons (e. g. trichloride, tetrachloroethylene, trichloroethane or Freon 12) are deadly for the dielectric. The electrical spark causes the hydrocarbons of the dielectric to combine with the chlorine atoms to form hydrochloric acid. A spark erosion machine must therefore never be cleaned with trichloride or a similar substance. It is better to use a few liters of dielectric for this purpose. Moulds that have been cleaned in trichloride must be absolutely dry before being mounted in the machine.

5. Acids, used to pickle the electrode, must not be allowed to get into the dielectric.

6. The hydraulic system of a spark erosion machine should be absolutely leakproof. Not more than 1–2% additions of hydraulic fluid should ever get into the dielectric, as the large amounts of additives in these oils will otherwise lead to malfunctioning. Machines with electric servo motors do not have this problem.

7. Leaks in the water cooling system of a dielectric unit lead to a „miraculous" increase of the dielectric and to rusty tables. IME dielectrics separate quickly and completely from water so the water can be drawn off from the bottom of the tank, or the dielectric can be ladled out after about one day. The dielectric can then be used again.

If you adhere to these rules when working with dielectrics, the dielectric can be used in microfiltersystems for up to 25 years.

14. The effect of spark erosion on metal surfaces

The formation of craters

In the process of spark erosion, an electrical potential between workpiece and tool is discharged and a spark jumps across the gap. At the point where the work piece is hit, the metal is heated up so much that it melts and evaporates. A crater is formed. One after another innumerable such sparks are sprayed on the workpiece, and one crater is formed next to the other. The diameter of the crater on the photograph is about 200 pm. The photographs were taken through an electronic microscope. To make the individual crater more easily visible a polished metal surface was used. The spark erosion machine was only switched on for a fraction of a second, so that the edges of the craters would not overlap.

Each of these craters has a typical edge with a thermically influenced zone.
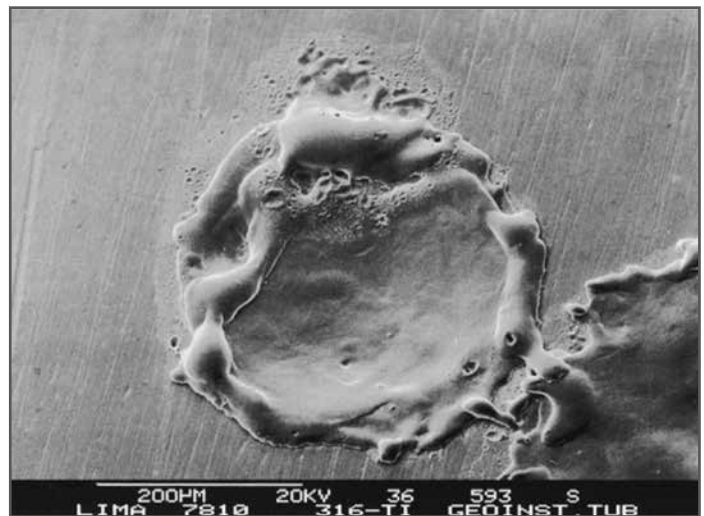
Here a crater on a titanium work piece is shown. A profile structure, formed by the rapid solidification of the heated titanium, can be clearly recognized. Part of the liquid titanium was flung into the dielectric.

Eroded surfaces

Characteristic of an eroded surface are the numerous craters with overlapping edges. In addition, microscopic eroded particles can be seen sticking to the surface.
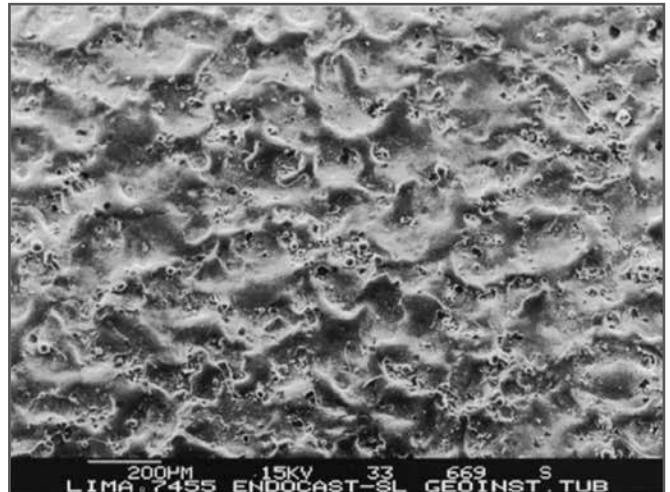
By enlarging the photograph one can clearly see the crater edges on the work piece and the microparticles sticking to them, as well as a hole in the surface of the metal.
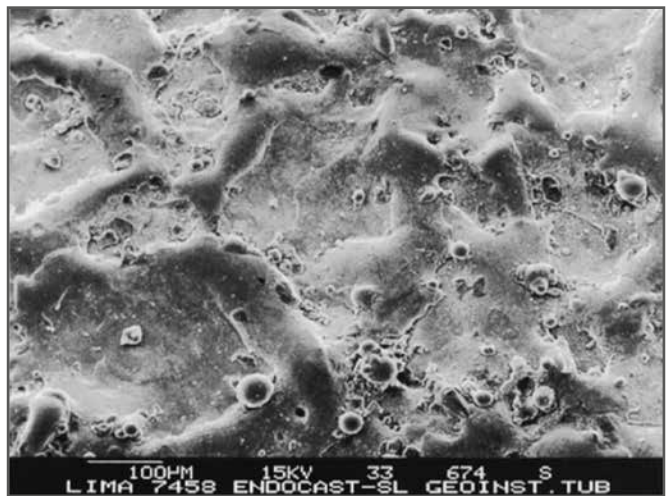
Enlarged once more one can see microscopic cracks emanating from these holes. These cracks are signs of an overheated surface.
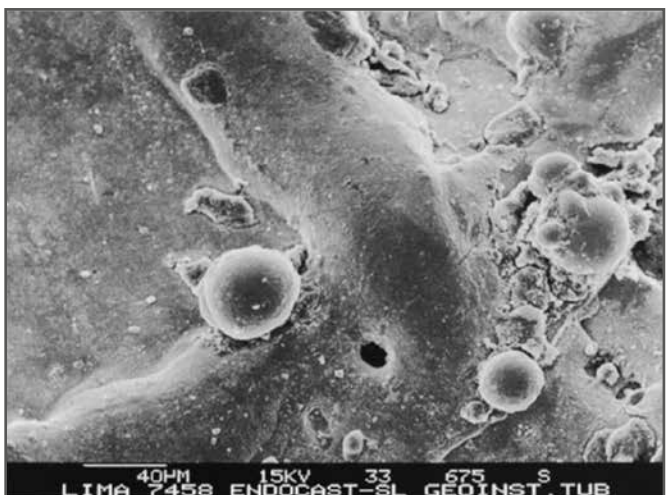
If the electronic microscope is used to make an even greater enlargement, these microscopic cracks become very evident. The eroded particles even begin to look „human". Eyes, ears and a mouth can be recognized.

Surface polished by means of spark erosion

If spark erosion is used to polish a surface, the edges of the craters are largely removed. A cross-section through a work piece polished by spark erosion clearly shows that there is only a very small white layer and that the influenced zone is only about 2 pm thick.
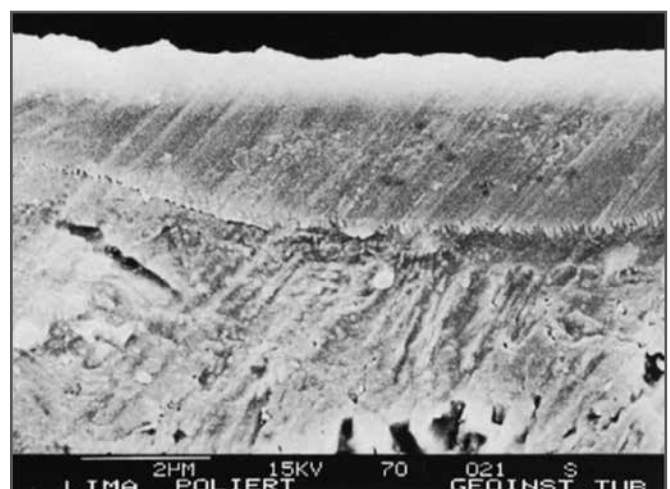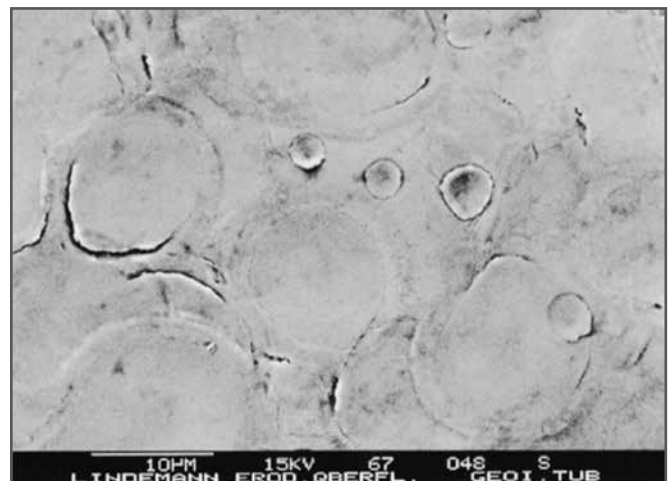
Eroded particles

Seen with the naked eye erosion sludge looks black. If the sludge of an erosion machine that works with different materials is washed out with acetone and then put under an electronic microscope one sees a great many larger and smaller balls.
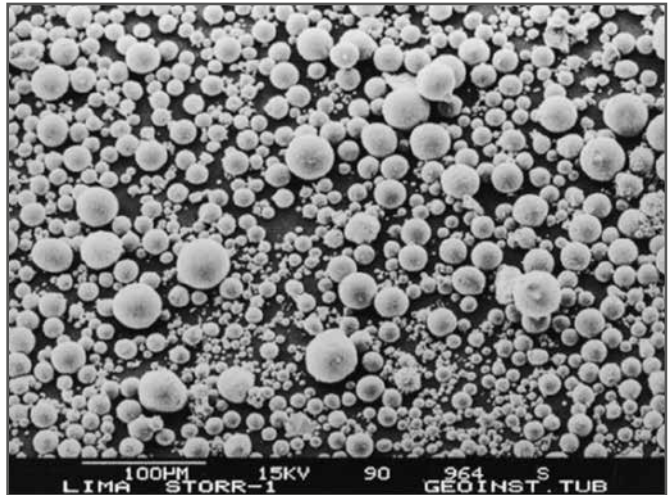
After enlargement differences between the eroded particles become evident. Thus three particles have melted together to form „triplets", a big particle has fused with a small one (mother and child), and many small particles have gathered together on a big particle because of electrostatic or magnetic force.
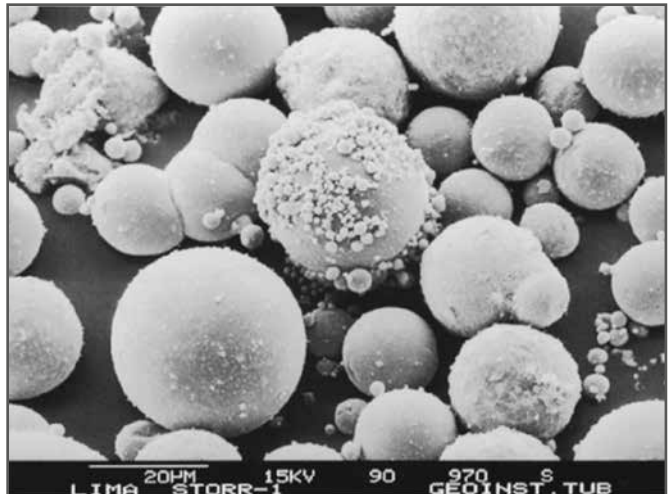
Some particles look like golf balls, or like our neighbouring planet Mars with its famous Martian canals.
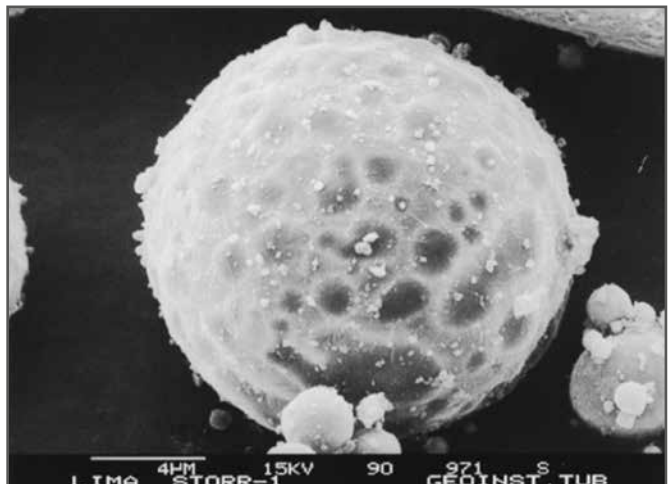
Other eroded particles have a textile structure ...

... or have velvety surfaces like peaches.
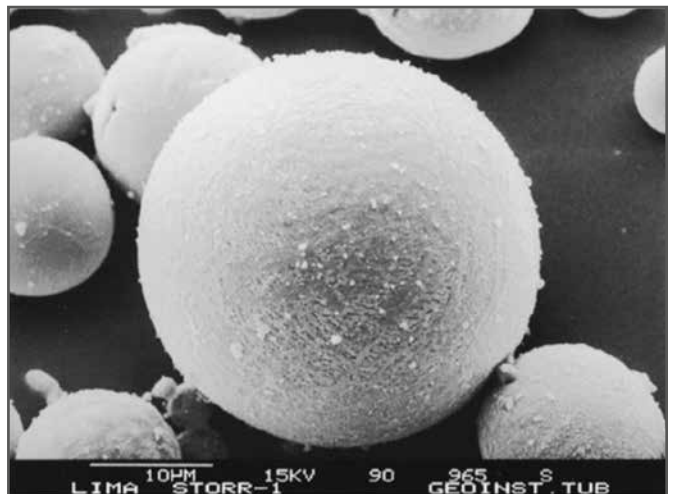
Many particles have a cavity on the one side because of the sudden shrinkage of the metal. If tool steel is used these microscopic balls are often hollow and have sharp edges that can injure the human skin.
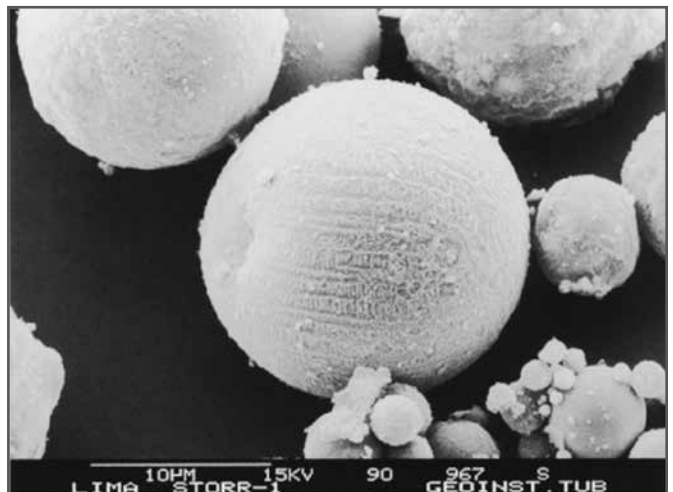
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oelheld UK Ltd.
Unit 16, Colomendy Business Park, Erw Las
Denbigh, LL16 5TA. • United Kingdom
Phone: +44 1745 814-777
E-mail: sales@oelheldgroup.co.uk
Internet: www.oelheld.com

oelheld technologies SAS
Technopôle de Forbach-Sud
140, Avenue Jean-Eric Bousch,
57600 Oeting • France
Phone: +33 387 90 42 14
E-mail: hutec-fr@oelheld.com
Internet : www.oelheld.com
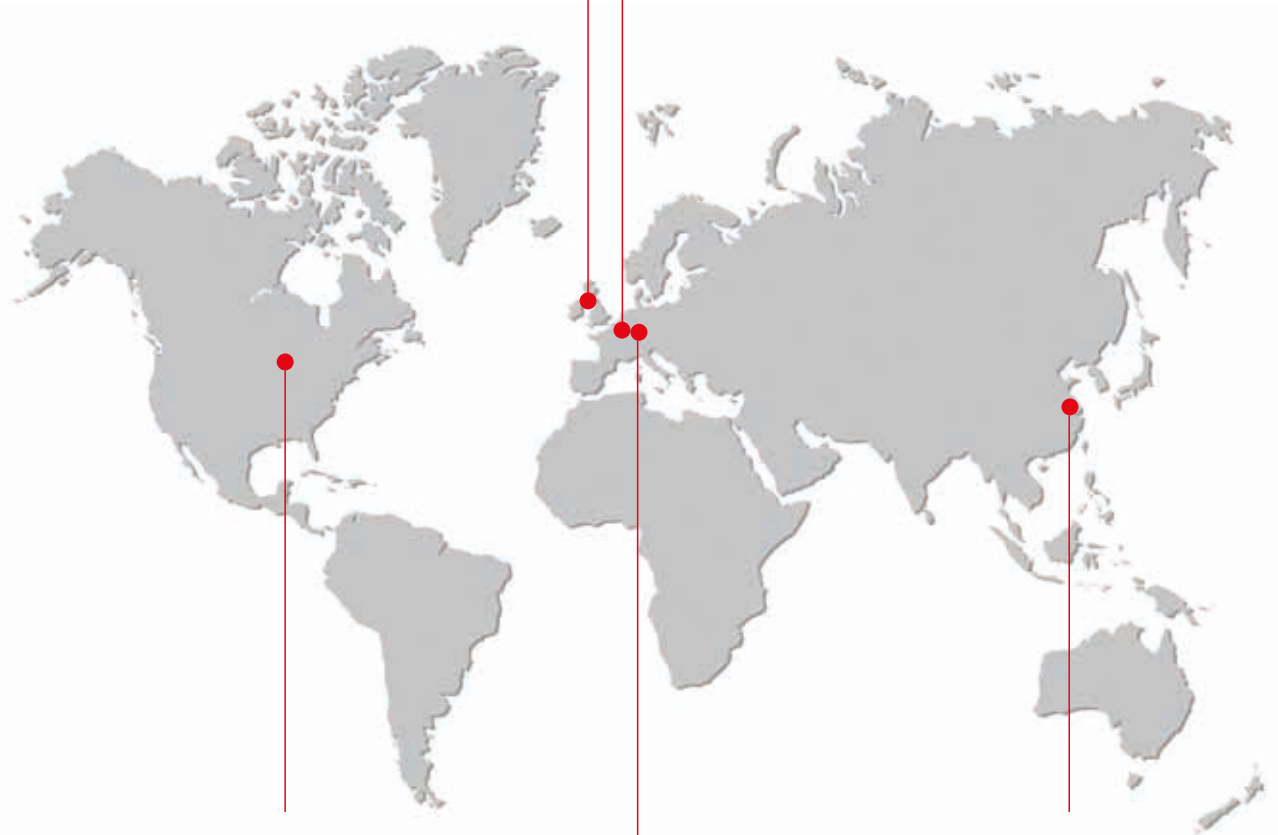
oelheld U.S., Inc.
1100 Wesemann Dr
West Dundee, IL 60118 • USA
Phone: +1 847 531 8501
E-mail: hutec-us@oelheld.com
Internet: www.oelheld.com

oelheld innovative fluid technology (Taicang) Co., Ltd
No. 5 Suzhou Road, Jiangsu
215400 Taicang • China
Phone: +86 512 8278 0027
E-mail: services@oelheld.com.cn
Internet: www.oelheld.com

oelheld GmbH
Ulmer Strasse 133–139
70188 Stuttgart • Germany
Phone: +49 711 168 63-0
E-mail: hutec@oelheld.de
Internet: www.oelheld.com

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oelheld®
innovative fluid technology

oelheld GmbH • Ulmer Strasse 133–139 • 70188 Stuttgart • Germany
Phone: +49 711 16863-0 • Fax: +49 711 16863-3500
E-mail: hutec@oelheld.de • Internet: www.oelheld.com

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