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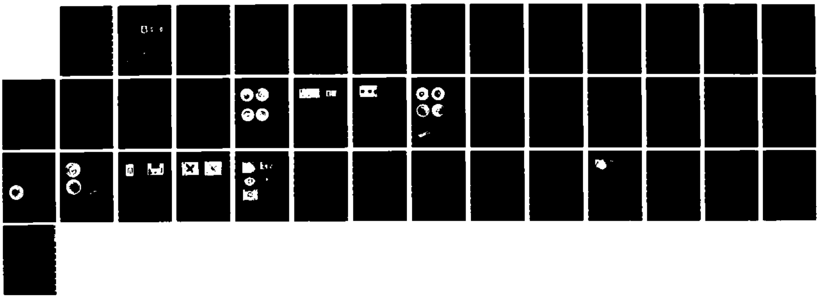

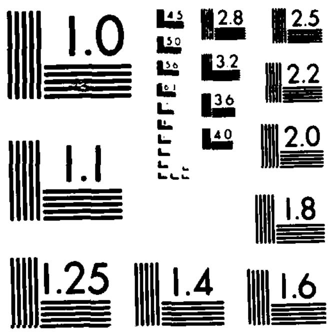

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THE MECHANISM OF ELECTRICAL EROSION OF METALS

by

S.L. Mandel'shtam, S.M. Rayskiy

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THE MECHANISM OF ELECTRICAL EROSION OF METALS

By: S.L. Mandel'shtam, S.M. Rayskiy

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> In them occurs the state named "night blindness" - hemeralopia, which, according to the current point of view, is a result of damage of the rod-shaped apparatus of the eye.
>
> Page 51.
>
> However, in recent years it has been shown that with the hereditary pigment degenerations in animals the biochemical changes are observed in all celluar elements of the retina.

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Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

Page 549.

The mechanism of electrical erosion of metals [1].

FOOTNOTE [1]. It is represented to report on session of department of physico-mathematical sciences of AS USSR. ENDFOOTNOTE.

S. L. Mandelstam and S. M. Rayskiy.

§ 1. Introduction.

With some forms of electrical discharge, in particular in condensed spark discharge, as is known, it occurs extensive destruction of both of electrodes or one of them. This phenomenon, which obtained the name of "electrical erosion", plays in the series/row of the practical applications of discharge very harmful role. It leads to the intense decomposition of high-voltage switches, contacts of relay, candles of the internal combustion engines and other discharge tools. At the same time, recently this phenomenon began to be utilized for metal working. On its use are constructed new, in the highest degree effective, method of cutting, drilling and other metal working, proposed by B. R. Lazarenko and obtained the name of "electric spark method". Considerable literature is dedicated to the phenomenon of electrical erosion. Partially the results of these investigations are summed in the known works of B. R. Lazarenko and N. I. Lazarenko [1] and monograph of Holm [2]. The very large material, which characterizes effect on the value of the erosion of material and form of the electrodes, parameters of discharge circuit, properties of the medium and other factors, is accumulated. A whole series of semi-empirical quantitative laws is obtained also. In spite of practical importance and there is physical interest, which in the phenomenon of "electrical erosion", the physical mechanism of this phenomenon up to now remains unexplained. Some researchers are inclined to assign paramount role in it directly to the processes of the thermal evaporation of the metal of electrodes [3], others - to the processes of electrolysis; hypothesis about the action of electrodynamic forces and series/row of other assumptions is voiced also.

It is undoubted, that phenomenon of electrical erosion is very complicated process, in which one way or another participate factors enumerated above. To us it seems, however that the fundamental phenomena of electrical erosion find to themselves the unconstrained explanation from the point of view of simple physical representation about the mechanism of the phenomenon, for which, as far as we know, up to now was not turned attention. We proceeded in this case from the following considerations. The examination of the existing material shows that the phenomenon of electrical erosion most is sharply pronounced in the high-voltage condensed spark discharge and in the low-voltage arc discharge with the shunting of arc by the great capacity (arc "in the spark regime").

During high-voltage spark discharge of capacitor/condenser basic part of energy, stored up on capacitor/condenser, is allotted, as is known, in to so-called arc stage of discharge. This stage flows/occurs with the voltage/stress on the discharge of the order of several ten volts and under the current strength, which reaches, depending on the parameters of discharge, hundred and thousands of amperes.

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Decreasing the value of voltage/stress, to which is charged/loaded the capacitor/condenser, and respectively increasing capacitance of capacitor, it is possible to obtain, also, in the low-voltage arc discharge in the "spark regime" the same current strength, as in the high-voltage discharge.

Thus, from point of view of electrical characteristics between high-voltage and low-voltage spark discharges, apparently, there is no fundamental difference; are analogous spectra of both types of discharge [4]. Consequently, the specific character of the spark discharge is not connected with the value of initial voltage/stress and the current strength, realized in the discharge. The vital difference of spark discharge, high-voltage and low-voltage, from the arc, is in the fact that in the spark discharge, because of the short duration of current pulses, the channel of the discharge does not manage any strongly to be expanded [5]. Therefore, in the spark discharge the current density reaches high values - on the order of

10^5-10^6 A cm^{-2}, whereas in the arc discharge it rarely exceeds 10^2-10^3 A cm^{-2}. This property of the spark discharge causes the specific special features of the channel of discharge - high temperature, which reaches by 10000-15000°C, which leads to the excitation of "spark lines", and the specific special features of the effect of discharge on the electrodes. These latter/last special features consist in the fact that because of the short duration of discharge separating on the surface of electrodes very high energy does not manage to be propagated in the metal any far. This entire energy is transmitted to the surface section of metal very small by the sizes/dimensions, which leads to its explosion-like evaporation. From the numerous investigations of the spark discharge it is well known that the formation of vapors of the metal of electrodes occurs in the form of the glowing jets or flames, which escape normal to the surface of electrodes at a velocity, which reaches several thousand meters per second.

Trajectory of flames can not coincide with trajectory of channel of discharge. For N. N. Sobolyev [6] it was possible to completely three-dimensional/space divide flames and channel and to investigate them. According to his data the temperature of flames reaches 10000°C. Fig. 1 (see insert I, page 552) depicts the photographs of several characteristic types of flames.

These properties of flames - high velocity of propagation and increased, as it will be shown below, pressure - make flames analogous to products of blast of explosives. Hence follows that these flames, obviously, must be they are capable of manufacturing the decomposition of the barriers/obstacles met by them, first of all - opposite electrode.

This decomposition there is, from our point of view, fundamental reason for erosion of electrodes. Electrical erosion thus is not connected directly with the electrical discharge, but it is the secondary process, caused by the mechanical action of the jets of vapors of metal, caused by discharge. This picture immediately finds to itself confirmation in the following very characteristic feature of the erosive phenomena - more extensive decomposition of the anode, than cathode; therefore, in particular, with the electric spark method of metal working workpiece it is switched on as the anode, and instrument - as cathode. Actually, from the investigations of flames it is well known that the flames, which go from the cathode, are considerably more intense than the flames, which go from anode [7] (see also Fig. 1b). This causes the more extensive decomposition of the anode by cathode flame in comparison with the cathode breakdown by weaker anodic flame.

From this picture, further, it follows that such regimes of discharge (low current density, large distance between electrodes) are possible, when flames will no longer be capable are capable of destroying opposite electrode. In this case it follows to expect larger cathode breakdown due to the stronger formation of flames and partial deposit of the material of cathode flame on the anode. During such regimes the value of erosion will be, obviously, considerably smaller. This phenomenon of the inversion of erosion is also well known. It was for the first time discovered and investigated by B. R. Lazarenko and it is developed in some modes of operation of the contacts of relay [8].

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§ 2. Experimental part.

Representations developed above about mechanism of electrical erosion as about process, caused by mechanical action of flames, allow/assume direct experimental check:

a) decomposition of both electrodes must rapidly be decreased with increase in distance between electrodes;

b) shadowing of flames, which prevents reaching/achievement by them of opposing electrode, also must decrease decomposition of this electrode;

c) destructive action of flame on opposing barrier/obstacle must be kept during three-dimensional/space separation of channel of discharge from flame;

d) creating conditions, which facilitate obtaining more sharply outlined flames, inter to reinforce their destructive action. Creating, further, the conditions, which prevent the rapid expansion of flames, it is possible to increase distance from the beginning of the flame, on which the flame retains its destructive action.

These experiments were realized by us. For convenience in the experimentation we utilized the high-voltage spark, connected according to the diagram, proposed by one of us [9], that makes it possible to change the length and other parameters of discharger, without changing the value of the energy, realized in the spark. The diagram of spark is depicted in Fig. 2. Capacitance value composed 1 μF, initial voltage across capacitor 10 kV. For the realization of aperiodic regime into the contour/outline the resistor/resistance, close to the critical (~5 Ω), was introduced.

Effect of the distance between the electrodes also of the sign of electrode on the value of erosion.

In first set of experiments effect on value of erosion of distance between electrodes also of sign of electrodes was studied. As electrodes served steel balls from the ball bearing as the diameter of 10 mm. The selection of electrodes was dictated by the following consideration. For the exception/elimination of the effect of the shape of surface of electrode on the intensity of flames, and consequently, and to their destructive action during the explanation of the role of the distance between the electrodes also of their sign it was necessary to use the electrodes of identical form, which have besides correct surface. Balls/spheres from the bearing are electrodes ideal from this point of view. It is ess^ntial also that on their polished surface the damages distinctly project/emerge.

Fig. 3 gives photographs of electrodes with low discharger, equal to 0.1 mm, and numerical length equal to 10000. Fig. 4 gives the photographs of the surface of balls/spheres with large discharger - 4 mm after 50000 discharges. As can be seen from photographs, the value of erosion with the wide interval (Fig. 4) is considerably less than with the low gap/interval (Fig. 3), in spite of the fact that the numerical length with the wide interval was considerably larger (50000), than with low (10000). With the low gap/interval the anode (b) is destroyed considerably stronger than cathode (a). With the wide interval the inversion of erosion occurred - cathode (a) was destroyed due to the formation of flame, and on the anode (b) in the center flange was formed from the material of cathode plotted/applied to the anode. Analogous results were obtained with copper and other electrodes.

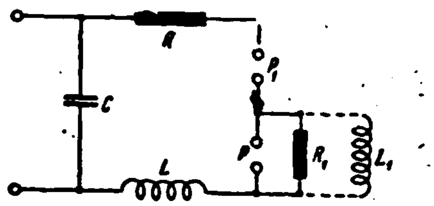

Fig. 2. Diagram of stable contour/outline with two sparks. Capacity/capacitance C is loaded through back-out resistor of R_1 or self-induction L_1 to the breakdown of the stable adjustable gap/interval P_1. After breakdown the voltage/stress is concentrated on the high resistor/resistance of R_1 (or L_1), which causes by the test/sample of the gap/interval P being investigated.

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Effect of form and material of electrodes on the value of erosion.

In our previous works on study of glow of flames during spark discharge was made observation, which on was published, that brightness of flames, their extent and correctness of form very depend on shape of surface of electrodes. It seemed that the application of a conical electrode, which is ended with point, is an indispensable condition of obtaining the sharply outlined long and bright flames. The electrode before each experiment must anew thoroughly be sharpened to the correct cone. It was explained that the reason for the effect of the form of electrode lies/rests not at the displacement/movement of the creeping discharge of electrode in the case, when it does not have a point, but it is connected with the special features of the formation of flame on the sharp conical electrode. Difference in the form of flame for the conical and flat electrodes one can see well in Fig. 1c (cementing in I). It was to be expected that the sharp conical electrode will give strengthening the effect of erosion on the opposite electrode. For explaining the effect of flame contour on the value of erosion the arrangement of electrodes, given in Fig. 5 (page 557), was used. Between two balls/spheres from the bearing the copper electrode, which has the diameter of 4 mm, is fastened/strengthened to the insulator in the cylindrical part. One end/face of electrode is sharpened to the acute cone, another - has spherical surface. Distances from the point of cone to the ball/sphere and from the spherical end/face to another ball/sphere are equal to each other. This arrangement of electrodes provides the possibility of the reliable comparison of the action of sharp/acute conical and blunt shape of surface. The decomposition, caused by sharp conical electrode, proved to be considerably more than than the decomposition, caused by blunt electrode.

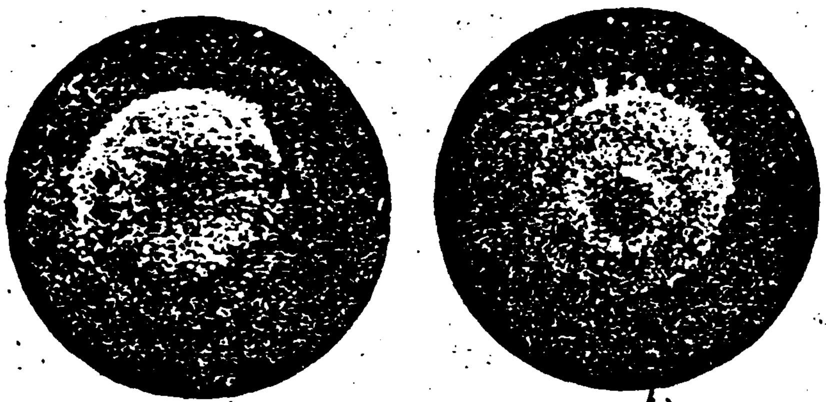
Effect of material of electrode, which creates flame, was further by us studied. We tested the series/row of the metals: iron, aluminum, magnesium and copper. It seemed that the greatest decomposition of the opposing electrode cause copper. Together with I. S. Abramson, we made consecutive photographs of discharge build-up between two conical electrodes. The exposure of order $1 \cdot 10^{-6}$ s made it possible to trace the dynamics of a change in the flame contour. It seemed that the flames of copper electrodes possess larger compactness and stability, than the flames of other tested metals. This special feature of the flames of copper explains large, than in other metals, the capability of copper for the decomposition of the opposing electrode. The photographs, given in Fig. 6 (see insert I), illustrate the aforesaid: a - depicts the discharge between the copper electrodes, b - discharge between the magnesium electrodes. In both photographs lower electrodes served as cathode, and upper - anode. In these photographs large compactness and flame stability in the case of copper in comparison with the flames in the case of magnesium is well visible.

Further experiments served for testing role of distance in mechanism of electromachining, but now they were manufactured already with sharp conical copper electrodes as sources of flames. Fig. 7 (page 557) gives the diagrams of the layout of the electrodes: a) at large distances, b) with the low distances, c) during the combination of low and large distances. This arrangement of electrodes also provides the possibility of the reliable comparison of the results of experiment.

Page 553.

a) b)

Fig. 3. Damage of steel ball-electrodes with low distance between them - 0.1 mm - after 10000 discharges: a) cathode, b) anode.



a) b)

Fig. 4. Damage of steel ball-electrodes with large distance between them - 4 mm - after 50000 discharges: a) cathode, b) anode.

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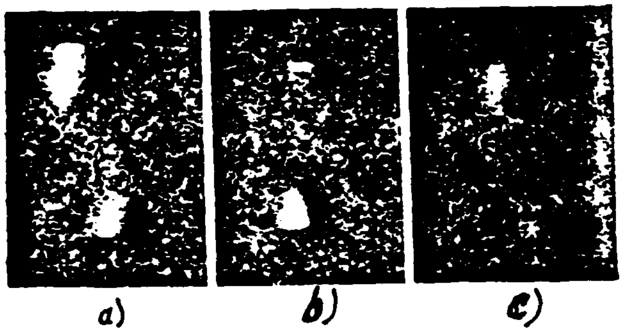

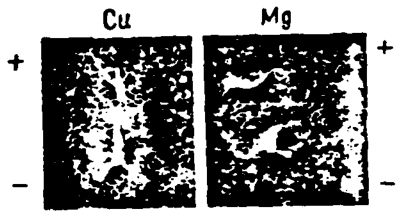

Fig. 1.

Fig. 6.

Fig. 1. Form of flames during capacitor discharge: a) flames are propagated perpendicular to surface of electrodes; oscillatory discharge; b) lower electrode - cathode, upper - anode; flame, which goes from cathode, is stronger than flame from anode; c) lower electrode flat/plane, upper - conical; flame is stronger in sharp electrode; oscillatory discharge.

Fig. 6. Effect of material of electrodes on value of flames: Cu - copper electrodes, Mg - magnesium electrodes; lower - anode. Flames are stronger in copper electrodes.

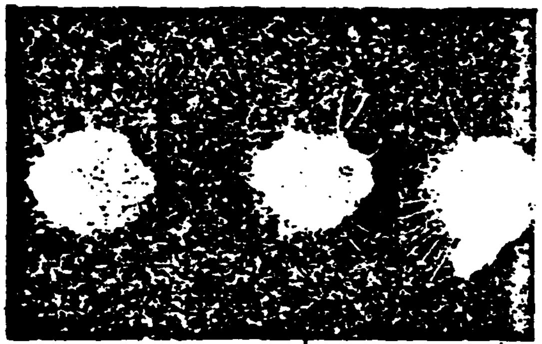

Fig. 9. Discharge between copper sharp conical electrode and steel plate: a) first discharge, b) second discharge, c) third discharge. After the first discharge the glow under the plate is noticeable - the plate with a thickness of 0.1 mm is punched right through.

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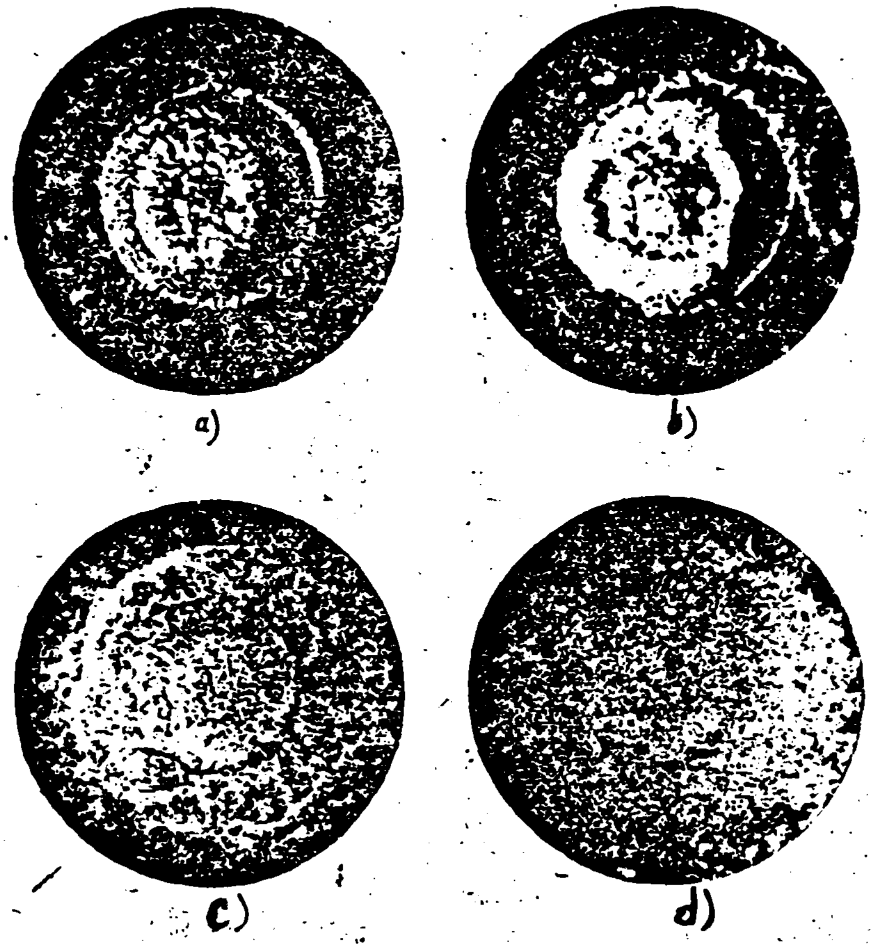

Fig. 8. Decomposition of steel ball by flame from copper sharp conical electrode after 300 discharges: a) with distance of 0.3 mm, cone served as cathode; b) with distance of 0.3 mm, cone - anode; c) with distance of 4 mm, cone - anode; d) with distance of 4 mm, cone - cathode.

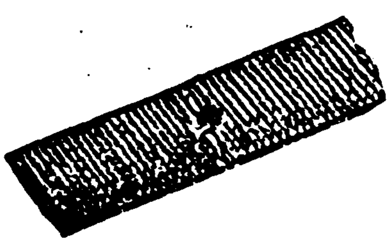

Fig. 10.

Fig. 10. Photograph of file, in which after several thousand discharges was formed hole with diameter of 5 mm and with depth of 2.5 mm.

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Page 557.

Under these conditions the role of the sign of electrode is not decisive, whereas the role distance between the electrodes, on the contrary, is very great. With very low discharger are visible deep funnels/hoppers, which were being formed on the balls/spheres, while at large distances of ball/sphere from the point of cone 0 fine/small surface damages in the form of pittings/ulcerations and droplets of metal. Numerical length was in both cases equal to 300. Thus, as before with the decrease of the value of gap/interval decomposition is reinforced. The extreme strengthening of the very effect of erosion from the sharp conical electrodes in comparison with the spherical electrodes as the source of flames is observed also. Thus, for example, decomposition, produced by acute cone during 300 discharges, exceeds the decomposition, produced by spherical electrodes during 10000 discharges. For the destructive parameter copper sharp conical electrode, switched on as cathode, tested its action on the thin steel plate, arranged/located at a distance of 0.1-0.3 mm. It seemed that under these conditions the steel plate with a thickness of 0.1 mm (blade of safe razor) is punched right through from the first or from the second discharge.

Fig. 9 (cementing in I, page 552) gives photographs of three these consecutive discharges: a) first discharge, b) second discharge, c) third discharge. Sharp conical electrode is arranged/located vertically, plate - horizontally. However, in the photograph the glow of vapors under the plate during the first discharge is evident, this shows that the plate was cleared right through. In photographs b and c are well visible peculiar showers, traces of the glowing grits of plate, which escape upon its decomposition.

With the aid of copper point of cone with low dischargers it is easy to obtain common for electric spark method of metal working strong damages of steel objects. Fig. 10 gives the photograph of deepening in the file, obtained as a result of several thousand discharges. Sizes/dimensions of the damage, given to Fig. 10, which follow: the diameter of hole 5 mm, the depth of 2.5 mm.

Shadowing of flames.

Mechanism of electrical erosion, at base of which lies/rests destructive action of flame from opposite electrode, must condition elimination of decomposition or at least noticeable decrease of decomposition during shadowing of flame.

Test work of this conclusion was made following method. Between the destroyed electrode - steel ball - and the source of flame - copper acute cone (Fig. 11a) - was placed the circular quartz plate with a thickness of 0.5 mm. On the edge of plate the bevel/facet was made. Kray plate enclosed from the ball/sphere the conical point of copper electrode, projecting/emerging above it on 0.1-0.2 mm.

Fig. 5.

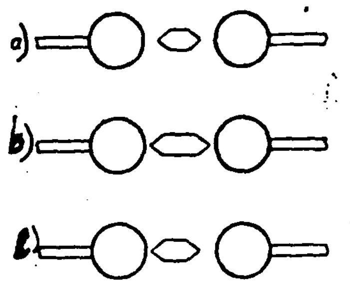

Fig. 7.

Fig. 5. Diagram of layout of electrodes for determining effect of their form on value of erosion.

Fig. 7. Diagram of layout of electrodes in experiments with effect of distance between sharp conical copper electrodes on value of erosion: a) steel balls at a great distance from electrodes, b) steel balls on low distance from electrodes, c) one steel ball/sphere at low distance from electrode, another ball/sphere at a great distance.

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Fig. 11b gives projection of copper conical electrode 3 and quartz plate 2 to ball/sphere 1; 4 - point of cone. Plate did not touch ball/sphere and point of cone. Under these conditions it is possible to expect that the direction of spark channel due to the presence of quartz plate is not changed, while the flames, which go from the point, to a considerable degree they are enclosed by plate. Experiments showed that the decomposition of ball/sphere proved to be negligible and it had very surface character. The contour/outline, which limits the damaged section of the surface of ball/sphere, in the precision/accuracy repeats the contour/outline of the unshielded part of the copper conical electrode (Fig. 12).

For control/checking following test was run. The selected numerical length with the screened flame first was accomplished/realized, then quartz plate was removed, against the point the new, adjacent section of ball/sphere was established/installed, and the same numerical length was repeated. Fig. 13 gives the photographs of the damage of the section of the surface of ball/sphere in the absence of shadowing (a) and in the presence of shadowing (b). Numerical length in both cases was equal to 600. Thus, the shadowing of flame almost completely removes the decomposition of opposite electrode.

Quartz plate, securing ball/sphere from decomposition, itself must undergo effect of flame. Its decomposition actually occurs. It is so considerable that during one of experiments with the shadowing of flame it was necessary three times to misalign quartz plate so that the flames would not reach ball/sphere. Fig. 14 gives the photograph of the plate, on which they are visible three damaged with the flames of the section of its edge.

Role of the expansion of flames and experiments with the electrodes, inserted into the capillary.

Rapid decrease of erosive action of flames with increase in distance between electrodes is naturally explained by expansion of flames during their removal/distance from electrodes. In order to interfere the expansion of flame, we artificially restricted its diameter, after concluding the cathode, made in the form of wire, into the capillary tube with a diameter of ~1 mm, made in the insulating material. The end/lead of the wire did not reach the end/lead of the capillary on 3-4 mm; the anode (flat steel electrode) was located near the end/lead of the capillary. The schematic of device is given in Fig. 15 (page 563).

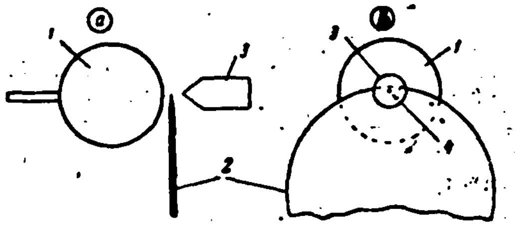

Fig. 11. Diagram of shadowing of flames: a) between copper sharp conical electrode 3 and steel ball 1 is placed quartz plate 2, in which on edges there is bevel/facet; b) projection of copper sharp conical electrode 3 and quartz plate 2 on steel ball 1. The point of cone as representative point 4.

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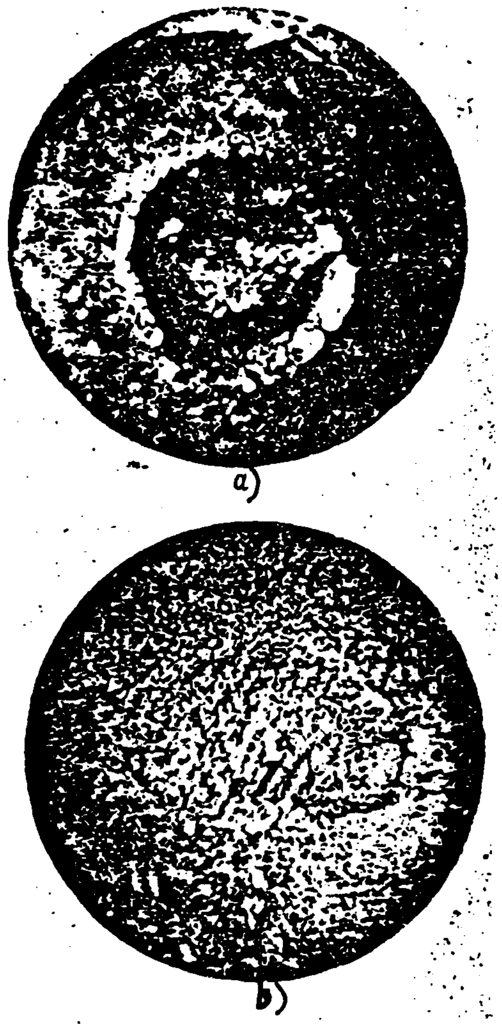
Fig. 12. Damage of steel ball, screened by quartz plate, by flame from copper conical electrode. Damages are not great and noticeable only that, where the ball/sphere is not screened by quartz plate.



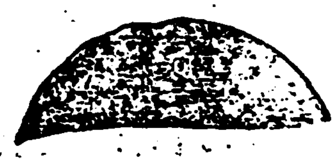


Fig. 13. Fig. 14.

Fig. 13. Damage of steel ball by flame from copper conical electrode: a) without shadowing of flame, b) in presence of shadowing.

Fig. 14. Damage of edge of quartz plate, which shielded flames.

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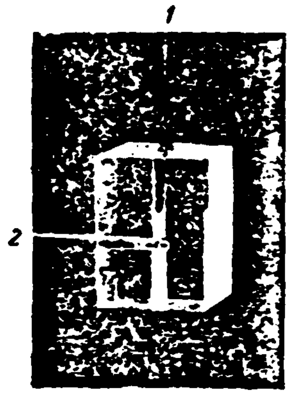

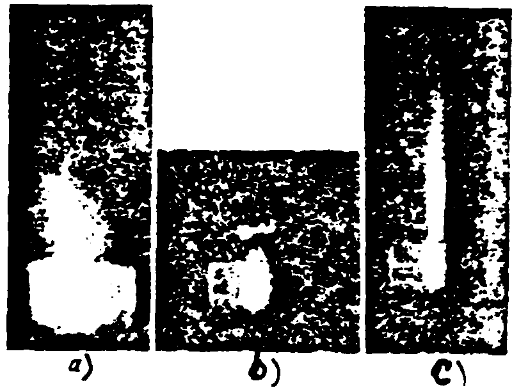

Fig. 17. Fig. 18.

Fig. 17. Discharger/gap, in which both electrodes are included into insulator: 1 - cathode, 2 - anode.

Fig. 18. Photographs of flame, which escapes from capillary, at different powers of discharge: a) at large powers of discharge, flame is unstable; b) at large powers of discharge, it is taken/removed with exposure in 2 μs; beginning of exposure 2.4 μs after breakdown of discharger; c) with decrease of power of discharge, flame is stable.

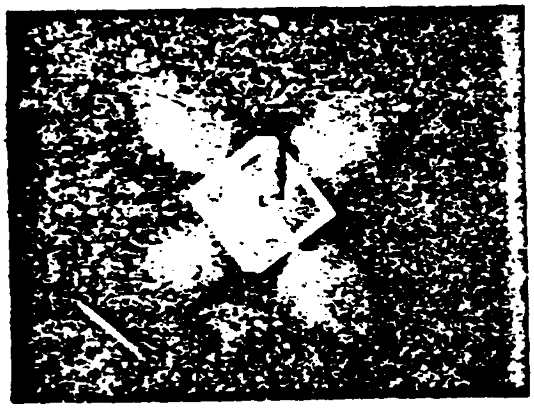

Fig. 19.

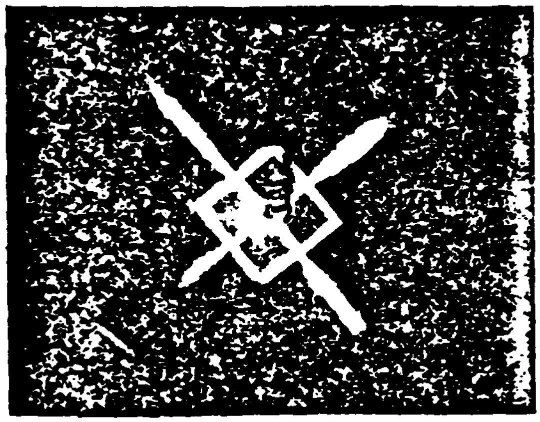

Fig. 20.

Fig. 19. Photograph of 4 flames, which escape simultaneously of 4 several those distinguishing by diameter and treatment surfaces of capillaries in discharger/gap, at large power of discharge; all flames are unstable.

Fig. 20. Photograph of 4 flames, which escape simultaneously from the same as in Fig. 19, capillaries with decrease of power of discharge; all flames they are stable.

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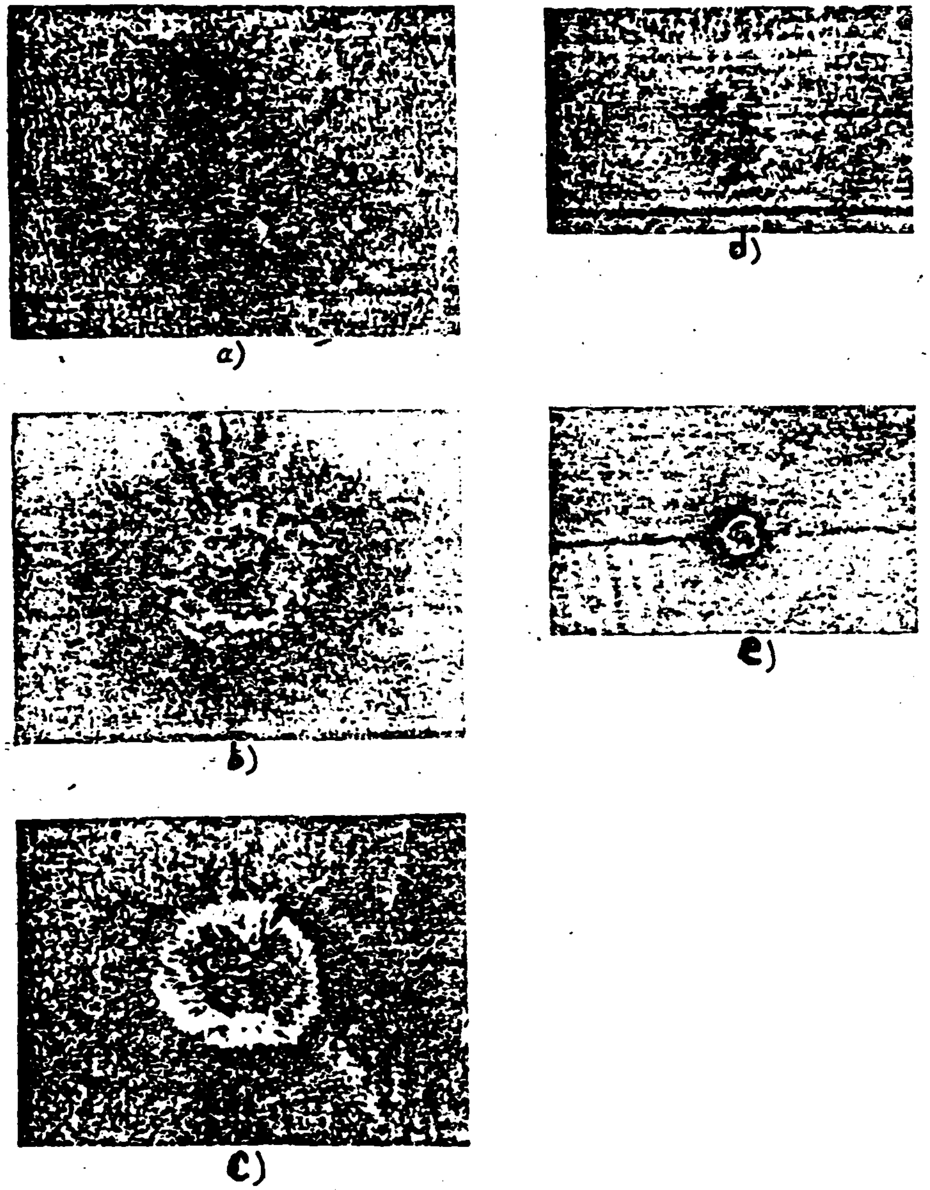

Fig. 16. Decomposition of steel plate by flame, which escapes from copper of wire-cathode, placed into capillary; single discharge: a) plate was located at a distance of 1 mm from hole of capillary, b) plate it was located at a distance of 0.5 mm from hole of capillary, c) plate was located at a distance of 0.2 mm from hole of capillary; d) decomposition of plate by flame from copper wire, not included in

capillary, with distance in 1 mm between plate and wire, e) decomposition of plate by the same flame, but with distance in 0.2 mm.

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Decomposition of steel electrode proved to be just as considerable as in experiments without capillary during close arrangement of both electrodes. Fig. 16 (page 561) gives the photographs of the decomposition of steel plate by the flame, which escaped from the copper wire-cathode, included in the capillary, with different distance between the end of capillary and steel plate: a - ~1 mm, b --~0.5 mm and c - 0.2-0.3 mm. (Let us recall that the wire does not reach the end/lead of the capillary on 3-4 mm).

For comparison in the same figure are given photographs of surface of steel plate, destroyed with flame from copper wire directly without capillary with different distance between wire and with plate: d - 1 mm and e - 0.2-0.3 mm.

In following experiments three-dimensional/space separation of channel and flame was produced.

In capillary, perpendicular to capillary with thin wire, which served as cathode (1), was introduced another wire - anode (2) (Fig. 17, see insert II - page 560). The flame, which escaped from the capillary, was directed to steel plate. Under these conditions the flame manufactured the same strong decomposition by that substituted toward the end of the capillary of metallic surface as in such a case, when this surface served as electrode. Flame exerted also the strong destructive action also on the glass, the porcelain, etc.

In other experimental variant wire electrodes were inserted in capillary one against another; products of discharge escaped from another capillary, drilled perpendicular to interelectrode gap/interval. The flame, which escaped from the lateral hole, was directed to the steel plate being investigated. The results of experiments proved to be previous and steel plate very badly failed itself with flame.

Form of flames, which escape from capillary and possessing destructive ability, is of interest. Their speeds exceed 2 km/s, they are unstable and immediately with the flight from the capillary they are expanded.

Fig. 18a (cementing in II) gives photograph of this flame. This photograph is obtained in the usual way, without the limitation of the exposure (flame it was removed/taken from the beginning of its glow to the cessation/discontinuation of glow). In Fig. 18b we give the photograph, taken/removed 2.4 μs after the beginning of the discharge with the exposure in 2 μs. This photograph makes it possible to judge the rate of the process of expansion and propagation flame, also, about that peculiar form, which the glowing parts of the flame accept.

Instability of flames at large power of discharge is their essential feature, it does not depend on random changes in experimental conditions. Thus, for example, if we release flames not of one, but of several lateral capillaries, varying several diameter and correctness of the surface of their side walls, then all flames will have on the whole identical form, which is evident, for example, in Fig. 19 (cementing in II).

Completely different form obtain flames with decrease of power of discharge by introduction to self-induction: they acquire stability and take form of flat bright jet (Fig. 18c). And in this case the form of flame does not depend on random variations in the test, as is evident for Fig. 20 (cementing in II), where were simultaneously released four flames of the capillaries, several which were being distinguished by diameter and shape of surface.

Such flat stable flames of erosive action do not manufacture.

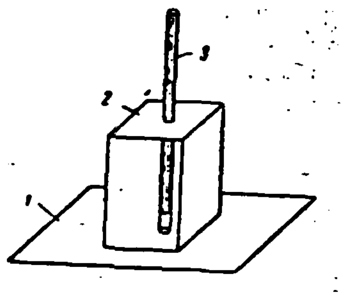

Fig. 15. Schematic of discharger/gap, which prevents expansion of flames: 1 - steel plate-anode, 2 - insulator with capillary channel, 3 - copper wire-cathode.

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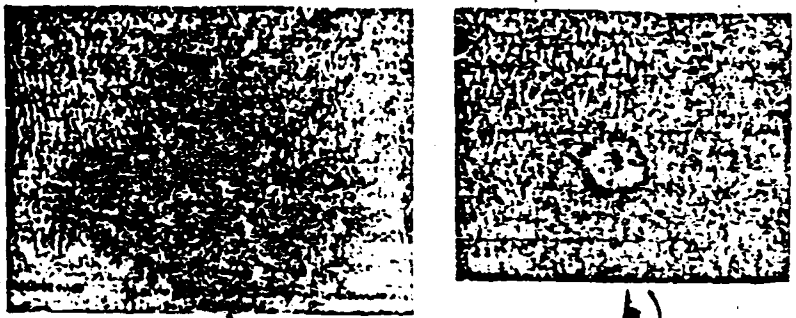
Intensification of erosion during submergsion of electrodes in liquid.

In technology of electric spark method of metal working it is known that decomposition of workpiece strongly increases during insertion/immersion of electrodes into liquid. Experiments with the electrode in the capillaries showed that with the distance between the end/lead of the capillary and second electrode on the order of 1 mm, when the decomposition of this electrode during the discharge in air is not already virtually noticeable, the discharge in the water gives extensive decomposition.

Fig. 21 gives two photographs of decomposition of steel plate by flame with identical discharger: a - when electrodes were found in air, b - when electrodes were found in water.

These experiments show that evidently, liquid limits channel, preventing, similar to capillary, to expansion of flame and reinforcing its destructive action.



a) b)

Fig. 21. Decomposition of steel plate by flame: a) in air (the same photograph, that in Fig. 16a, b) in water.

§ 3. Conclusion.

Totality of the described by us above diverse experiments, as it seems to us, it sufficiently convincingly confirms hypothesis advanced above about mechanism of electric spark erosion of metals as about secondary process, caused by destructive action of flames on opposite electrode.

Essential condition of realization of this mechanism, apparently, is motion of flames with supercritical rate. As it follows of the aforesaid above (page 563), the flames, which generate decomposition, immediately after flight from the capillary are expanded in the directions, which indicates the presence in flame of large pressures. The flames, which do not generate decomposition, retain the form of jet at a great distance after flight from the capillary, which indicates their subcritical rate. However, as far as the very mechanism of the destructive action of flames is concerned, this question is not yet explained; the possibility is not excluded that the processes, analogous to the cavitation decomposition of metal, here play role. The following essential, not explained another question - this is the question of why upon the intense decomposition of opposite electrode the decomposition of its own electrode is considerably less. Evidently, the explanation of this phenomenon lies/rests at the fact that the increase of "blast" on the electrode occurs more slowly than the stop of the moving/driving flames by opposite electrode. Thus, with the equality of pulses/momenta on both electrodes the pressure, exerted by flames to its own electrode, is less than on the opposite barrier/obstacle.

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A comparatively slow increase of "blast", naturally, is explained by the slow build-up of the current of spark circuit, by the caused high value of capacity/capacitance and by the need for the heating of the finite mass of the "detonated" metal.

One should note that are possible such cases, when during interrupting of arc, not shunted by capacity/capacitance, current density during first 10^{-6}-10^{-5} s, as it was shown recently by hill [10], can reach due to formation of bridges of metal of values, characteristic for spark regimes, i.e., here it can be accomplished/realized more extensive decomposition of anode, than cathode. Evidently, this phenomenon is the basis of the electromechanical method of working the metals of V. N. Gusev [11] [1].

FOOTNOTE [1]. Note to the correction. According to latter/last data [12] current density during first 10^{-5}-10^{-6} s can reach the values of 10^{5}-10^{6} A cm^{-2}. ENDFOOTNOTE.

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