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CLASSIFICATION FEATURES OF THE FORMS OF THE APPEARANCE OF ELECTRICAL EROSION

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FOREIGN TECHNOLOGY DIVISION

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13. ABSTRACT

At the writing of this article there was no clear definition of electrical erosion because of the lack of knowledge of such phenomena. Electrical erosion forms are classified by: a) physical features of the erosion-process mechanism, b) macroscopic changes on electrodes occurring during the erosion, c) the features and characteristics of the initial causes of the erosion process. The following types of erosions are classified and discussed: electrical erosion, break-contact erosion, mast c erosion, electrically explosive erosion, contactless erosion, gas-discharge erosion, plasma erosion, erosion in arc discharges, erosion in glow discharges, erosion in spark discharges, and erosion in pulsed-arc discharges.

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
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

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

CLASSIFICATION FEATURES OF THE FORMS OF THE APPEARANCE OF ELECTRICAL EROSION

K. K. Namitokov

The absence of a clear definition of the phenomenon of the electrical erosion of materials is caused on the one hand by the inadequacy of our knowledge of the physical mechanism of destruction both in those cases when the term "electrical erosion" is applied to certain of the phenomena of the destruction of materials and in other cases when the destruction of materials, similar in mechanism, is named otherwise [1]. On the other hand, such a state involves the absence of the systematization and classification of various appearances of electrical erosion.

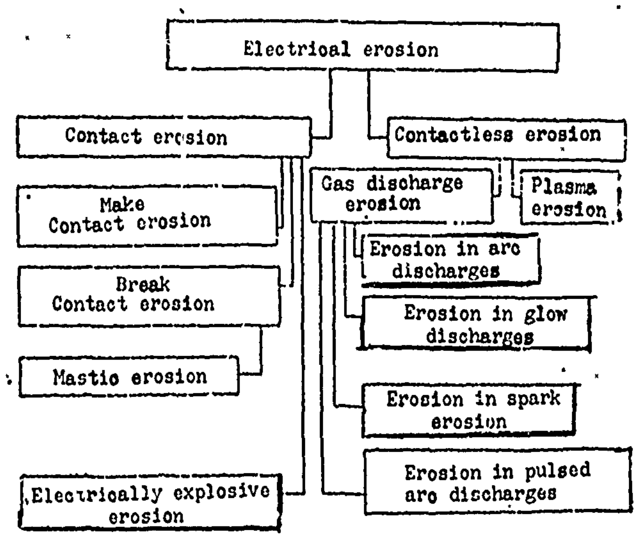
Forms of electrical erosion can be classified a) according to the physical features of the mechanism of the erosion process, b) according to the nature of macroscopic changes on electrodes which occurred during erosion, i.e., from final results detected at the end of the process, and c) from the features and characteristics of the initial causes of the erosion process.

Classification according to each of these principles will have its disadvantages. Thus, if we take the first principle as a basis there appear difficulties involving the fact that in a single act of erosion several mechanisms can be superimposed on each other whose clear delimitation is not always possible. If we take the second principle as a basis, here again cases are possible in which a single final result can generally be obtained with various erosion mechanisms. This is partially related to the third principle. However, from a comparison of various drawbacks and difficulties arising in attempts to classify according to each of these principles we can draw the conclusion that the last one is nevertheless most acceptable, especially if we consider the traditions and terminology which have already been compiled.

Let us examine the classification features of various forms of the appearance of electrical erosion, taking as our basis the distinguishing characteristics of its causes. All basic variants of the electrical erosion of materials can be divided into two large classes: 1) contact erosion, 2) contactless erosion. By the term "contact erosion" we mean all those forms of erosion when the contact points of current lines are disrupted on attaining a through-current density above a certain value. Here, basically those forms of erosion are related which are observed at the points of contacted electrodes during the passage of current between them. They are of two varieties: a) make-contact erosion, and b) break-contact erosion. In turn, break-contact erosion had the so-called "bridge erosion" in its subdivision.

The form of erosion observed at the contact points of current lines, in monolithic conductors (for example, in narrow necks of fusible inserts of safety devices) during an excess of a certain value of current should be related to the first class. This form of erosion can be called "electrically explosive erosion" in order to emphasize its distinction from "purely contact" erosion.

All those varieties of erosion observed with the absence of direct contact between electrodes can be related to the second class of erosion forms, i.e., "contactless erosion." These are primarily those forms of erosion which are observed during electrical discharges. They can be called "gas-discharge erosion." Those forms of the erosion of metals (and materials in general) observed during the interaction of electric-discharge plasma ("plasma erosion") should also be related to contactless erosion. A typical classification diagram is shown below.



Let us briefly examine the features of the various forms of erosion and the conditions under which they appear in "pure form."

I. CONTACT EROSION

A. Make-Contact Erosion

When electrodes (contacts) make, if the voltage between them is less than a certain critical value during which the breakdown of the interelectrode gap is not possible, up to the moment of their physical contact there can be no electric discharge. But on the electrode surface at the points of their initial contact the current density can reach very high values. As a result, due to the Joule heat the material of the electrodes can not only melt but be brought to higher temperatures at which evaporation and an explosive removal of the material is possible. If an electrical breakdown of the gap is possible before the moment of physical contact of the electrodes, the discharges brought about after this can cause a noticeable erosion of electrodes proceding the process of contact erosion proper. The intensity of the make-contact erosion will obviously depend, on the one hand, on the properties of the electrode material, and on the other hand it will depend on the make conditions and the electrical parameters of the circuit. Thus, for example, at a high approach rate a fusion of surface microsegments leading to a redistribution of the material from these segments along the electrode surface will be observed but without the removal of a noticeable amount of substance from them [1]. If, however, the electrodes approach at a relatively low rate, not only a fusion of large volumes on the electrode surface but also an electrically explosive destruction of a large amount of the substance is possible.

B. Break-Contact Erosion

When electrodes (contacts) break, the process occurs, as it were, in reverse order. At a low rate of the parting of the electrodes, in gradually decreasing areas of physical contact of the electrodes under the effect of through current heat is released which can melt noticeable volumes. Further development and occurrence of the process will be determined depending on the electrical and kinematic parameters and physical properties of the electrode material. Conditions are possible in which the melted mass is extracted, during the divergence of the electrodes, in the form of a fluid bridge which, depending on the indicated conditions, can be destroyed electro-explosively or by relatively quiet evaporation. Also possible is the explosion of the bridge without any noticeable removal of the material but with the advantageous transfer of it from one electrode to the other (i.e., the so-called bridge transfer [2]). If the electrical parameters of the circuit are such that the excitation and existence of electric discharges between the electrodes are possible, erosion in the electric discharges is superimposed on the break-contact erosion (as in the first case with the electrodes' making contact). In this case contact erosion prepares favorable conditions for bringing on discharges and intensifying the gas-discharge erosion following them.

C. Electrically Explosive Erosion

All possible processes of "electrically explosive erosion" are not characterized by any one single mechanism just as electrical erosion processes in general. In the latter case the nature of the occurrence of the erosion processes depends to a great extent on the rate of change of the resistance of the contact points of the electrodes' contact, i.e., on the approach or divergence rate of the electrodes, while with "electrically explosive erosion" there is observed a similar picture involving the rate of the supply of energy to a short fusible neck, but due already to a current increase. According to this, by analogy with the classification scheme of Chase and Levine [3], "electrical erosion" can be divided into four cases:

1. A very slow supply of energy when difference ΔW between the energy fed to a unit volume of the neck per unit and the energy tapped from it (for example, due to heat conductivity) is greater than the energy necessary for melting but less than the energy necessary for evaporation. Then the "electrically-explosive erosion" is completed by the process of melting the neck without evaporation.

2. A slow supply of energy when ΔW already becomes adequate for evaporation; however the rate of supplying the energy is still inadequate to assure a rapid explosion. In this case destruction occurs by partial evaporation at the contact points of instability in the melted neck and its decay into relatively large drops.

3. A rapid supply of energy when ΔW is greater than the energy necessary for evaporation, while the rate of supplying energy is such that it does not have time to bring about the development of instability in the melted neck. In this case explosive evaporation occurs.

4. A very rapid supply of energy when the time for reaching the value of ΔW adequate for evaporation is less than the so-called electrothermal time constant. In this case, even before reaching the temperature on the neck axis equal to the evaporation temperature there occurs an explosive breakdown during which a noticeable role can be played by the electrodynamic effects and the thermal impact leading to mechanical breakdown.

After "electrically-explosive erosion," the further course of the development of the process is determined by the "gas-discharge erosions" formed by the electrodes (residues of a melted insert in case of safety devices).

2. CONTACTLESS EROSION

A. Gas-Discharge Erosion

The forms of electric discharge [4] in which various forms of gaseous erosion appear most prominently are as follows: arc, discharge, glow-discharge, spark-discharge, and pulsed-discharge [1]:

a. Erosion in arc discharge. Freely speaking, an open electric arc is characterized by a relatively low temperature in the discharge channel, a large diameter, and, consequently, a rather low energy density per unit volume. Traces of the discharge channel on the electrodes (erosion traces) are accordingly smeared along the electrode surfaces and are relatively shallow. With an increase in the duration of the burning of the arc and the power of the electric circuit these changes naturally intensify, the electrode surface fuses and is scorched, and splashes of molten metal are formed along with vapors which are partially carried out of the intercontact gap and again partially precipitate on them. When the fused elements of the safety devices burn out an arc is formed which then destroys the residues of the inserts which play the roles of electrodes as under the ordinary conditions of arc combustion. The basic difference of the processes is caused by the presence of a filler and of increased pressure in the frame.

b. Erosion in a gas discharge. A gas discharge is characterized by considerably less current density than in an arc discharge. The gas discharge also causes erosion of the electrodes, especially of the cathode, called cathode sputtering [5]. Cathode sputtering occurs as a result of the "evaporation" of atoms with a very localized (within the limits of atomic lattices) segments of the cathode caused by impacts of positive ions because of the cascade deflection of solid atoms. It does not cause the characteristic traces (pits) of destruction. The intensity of the destruction is negligible as compared, for example, with the arc discharge.

c. Erosion in a spark discharge. With relatively small gaps and sufficient power a spark discharge at the contact points with the channel also causes erosion of the electrode surface. The localization of the erosion process and the depth of the damage are characteristic for this form. This is caused by the low duration of the process in which the channel of the spark discharge does not have time to expand or shift along the electrode surface very significantly. The high temperature in the discharge channel leads to concentrated and deep damage to the surface. Moreover, the short duration of the passage of the spark discharge adds the nature of an explosion to the erosion process with the selection of erosion products at a high rate.

d. Erosion in a pulsed discharge. Between spark discharges (at relatively low voltages on the electrodes on the order of 10^3 V) and low-voltage pulsed discharges (brought about by a discharge of a capacitor at voltages of several hundred volts) there exist certain common features - low duration, high temperature in the discharge channel, high current density, etc.

In accordance with this, common features and similarities also appear in erosion phenomena caused by spark discharges brought about on relatively short interelectrode gaps, i.e., with very low voltages (within the limits of no more than several thousand volts) and by low-voltage pulsed short-duration discharges.

Electro-erosion phenomena during these discharges is always characterized by more or less localization on portions of the electrode surface, depending on the discharge energy and its duration. Under certain conditions of turning on the instruments, vibrations of the contacts with the breaking of the electric circuit can lead to the excitation of pulsed discharges between them having a pulse duration less than 10^{-2} s (determined by the frequency and amplitude of the vibration of the contacts). Under other conditions, for example, with the deflection of greater currents between contacts there can appear an electric arc in the atmosphere of the surrounding medium and in the easily ionizing vapors of the contact material with a long ($\geq 10^{-2}$) duration of combustion, depending on the rate of the spacing of the contacts, the properties of the contacts and the medium.

In the first and second cases of commutating the electric circuits the excitation of an electric discharge causes a more or less intense erosion of contacts. The nature of the erosion in these two different cases differs one from the other. This is caused by the fact that when the circuits are made under conditions of the vibration of the contacts, as has been indicated, the electric discharge is pulsed. Traces of erosion in this case ordinarily have a more or less localized nature in the form of pits with dimensions depending on the duration and energy of the pulse. In the second case (partially in the first case when the vibration frequency is relatively low, and the amplitude is high) the discharge can have time to stabilize, and then an arc discharge is formed with a discharge channel extended in diameter and shifting along the contact surface, leading to erosion with smeared traces of distruction on the contacts.

B. Plasma Erosion

Unlike all of the above variations in the forms of electrical erosion, not only conductors but also nonconductors can be subject to plasma erosion. With the plasma erosion of conductors two cases are possible. The first is when a plasma jet (or a cloud of plasma in general) forms a galvanic bond of the current source with the material on which it acts. This takes place, for example, with the motion of a column of plasma along arc-arresting corners of contact systems of electrical instruments after the arc is ejected from the intercontact gap when the contacts are broken. In this case the effect of the current proper, "shunted" across the plasma, is also superimposed on the "gas-kinetic" effect of the plasma on a conductor. The significance of the latter in a genera_ erosion act depends on specific conditions.

In the second case when the plasma and conductor on which it acts do not form a galvanic bond with the current source, the basic mechanism of energy transmission from the plasma to the surface of a solid is the "gas-kinetic" effect, the effect from the radiation of the plasma, and also possible exothermic reactions on the surface under the effect of the plasma, and recombination processes (involving the yield of energy during recombination and molecules of atoms dissociated in the plasma, the recombination of ions and electrons on the surface, etc.). The energy-extracting mechanism is also the same when plasma reacts on the surface of nonconductors, as takes place, for example, with the entrance of arc plasma into arc-arresting insulation chambers of electrical instruments. The nature of the transmission of energy from the plasma to the surface of a solid and the heat processes on it associated with this substantially depend on the make-up and properties of the plasma and on its enthalpy. In practically all cases of the form of plasma erosion in question we are dealing with the so-called low-temperature plasma. But the range of temperatures encompassed by this term is very wide (from several thousands to tens of thousands of degrees).

An important role in the plasma-erosion process is played by the mechanism for removing the substance from the surface of the zones of damage by the primary effect of the plasma. With the quiet and prolonged existence of a plamsa cloud over a solid surface (under the condition of the adequacy of specific thermal power transmitted to the surface) the destruction process occurs basically by gradual evaporation. With moving plasma (under the effect, for example, of a magnetic field, as takes place in electrical instruments) mechanical forces (arising from the gas and plasma flows), which cause the atomization and blowing of molten material, also participate in the erosion process. All of these features also appear in the nature of solid surface destructions observed during plasma erosion and in the structure of the traces of plasma motion along it.

During the pulsed effect of plasma (ordinarily a specially formable concentrated plasma jet) the destruction process can occur intensely and will bear an explosive nature just as in the above-described erosion forms (if the heat flows created by them will be equivalent). Let us note that in the latter case a considerable contribution to the plasma-erosion process can be given by the kinetic energy of the flows of the jets themselves.

Surface destruction will occur when the thermal power transmittable to the surface by the plasma will be greater than the thermal power withdrawable from it (basically mechanical heat conductivity), which, other conditions being equal, depends on the thermophysical properties of the material.

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