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CONSIDERATIONS REGARDING THE INFLUENCE OF SOME PARAMETERS IN THE CASE OF ELECTROHYDROIMPULSES DRAWING

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Abstract: The paper presents the results of the author`s experimental research concerning the influence of discharge voltage and capacity of condensers battery, discharge axis - plate distance, the material and geometry of the electrodes or of the exploded wire and electrode gap on the shock wave maximal pressure and, implicit, on drawing depth which can be realized to the plate, in the case of electrohydroimpulses drawing in the high voltage domain, between 20...50 kV, in a cylindrical universal discharge chamber. Also, some considerations regarding the influence of gas bubble pressure are presented.

1. INTRODUCTION

Electrohydroimpulses drawing represents a technological alternative completing the range of cold plastic strain procedures. It is based upon the so-called technique of high energies-bearing impulses. Are known studies being done on the parameters which influences the size and the distribution of pressure in discharge chamber, for discharge voltages under 15 kV. But for high voltages, the studies are in small number and, in a large measure, incomplete or contradictories.

From this reason, for discharge voltages between 20…50 kV, has been examined for an influence study, those parameters which are considered to be of great importance from technological point of view and which, due to the construction of the deformation equipment, can be set in certain limits. Nevertheless, working in both mono and multiimpulse regime, these parameters are:

- the charge voltage of condensers battery;
- the condensers battery capacity;
- discharge axis - plate distance and electrode gap;
- configuration of the exploding wire;
- the material, the geometry and the diameter of the used electrodes (in the case of discharge with direct impulse breakdown of discharge space).

Present paper wishes to study the dependence of shock wave front maximal pressure on the parameters listed on the points above. The parameters listed on the first three points are called geometrical and electrical parameters.

The practical "forming window" in a metalforming operation is usually limited by necking or tearing problems on one hand and wrinkling on the other. An increase in ductility can be explained, at least partially, on the basis of inertial stabilization of neck growth during high-rate forming. Note that since there is a significant increase in ductility with velocity for many materials, forming limits of those materials become a function of the metalforming velocity. Therefore, efforts to predict forming capabilities of methods operating in the range of high forming velocities must include this effect.

2. EXPERIMENTAL RESEARCHES FOR GEOMETRICAL AND ELECTRICAL PARAMETERS

In some of the author's previous papers [2] had been presented the construction parameters of the own designed universal discharge chamber used in the experiments and also, of the electric system whereon the chamber was coupled (russian origin, model GIT 50 – 5x1/4C). The sensing device system for the shock wave front pressure measurement was also designed and manufactured by the author.

The variation of shock wave pressure relative to discharge voltage of condensers battery was presented in fig. 1 and 2, for different combinations of discharge circuit parameters, to a capacity equal with 8 μF (where **h** - discharge axis - plate distance; **l** - electrode gap; **U₀** - discharge voltage of condensers battery through spark discharger; **P_{us}** - shock wave maximal pressure; **C** - the condensers battery capacity; there were is no specification, the indicated dimensions for **h** and **l** are given in mm).

In fig. 3 are presented the dependence diagrams of pressure related to the discharge voltage, for three values of condensers battery capacity. The capacity was modified by conecting or disconecting some groups containing two condensers from the generator unit.

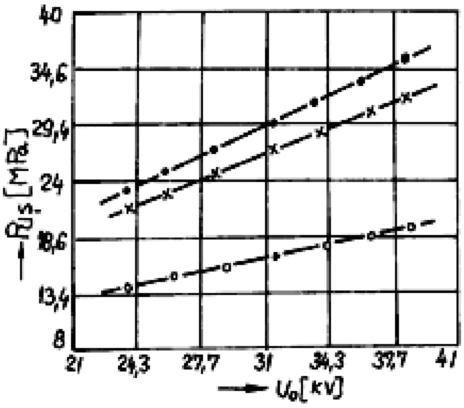

Fig. 1. The variation of shock wave pressure relative to discharge voltage of condensers battery.
h = 200; • l = 50; ° l = 35; x l = 80

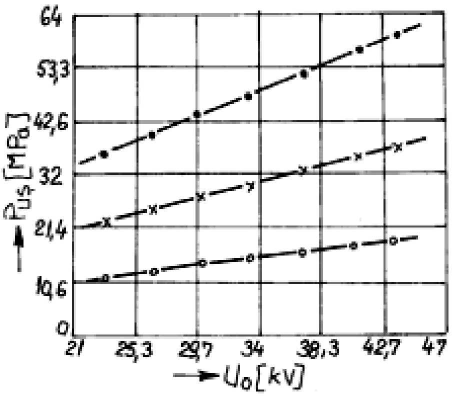

Fig. 2. The variation of shock wave pressure relative to discharge voltage of condensers battery.
l = 40; • h = 90; ° h = 250; x h = 160

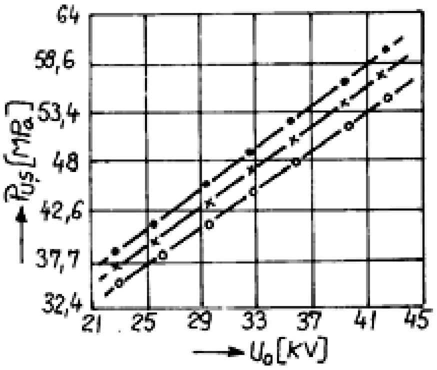

Fig. 3. The variation of shock wave pressure relative to discharge voltage of condensers battery.
h = 80 mm; l = 50 mm
• C = 8 μF; ° C = 4 μF; x C = 6 μF

The dependence of pressure related to the discharge axis – plate distance *h*, is presented in fig. 4 and 5, for different values of discharge voltage and electrode gap.

In fig. 6 and 7 are presented in comparision the pressures on shock wave and gas bubble, for two values of the charge voltage of condensers battery. The experiments [4] shown that, at increasing of voltage, to the same values of electrode gap, the pressure of gas bubble tend to be equal to that of shock wave. This explains the intense increasing of the maximum drawing depth values, for distances $h \approx (1 \ldots 1{,}3) \cdot l$.

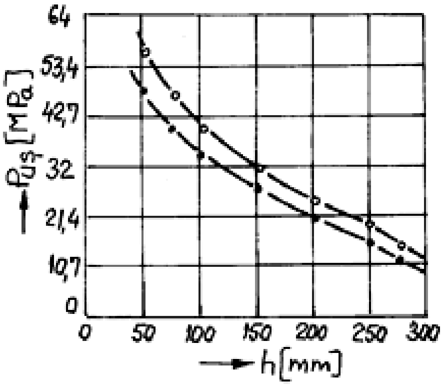

Fig. 4. The variation of shock wave pressure relative to discharge axis – plate distance.
I = 50 mm; • U_0 = 23,6 kV; ° U_0 = 30 kV.

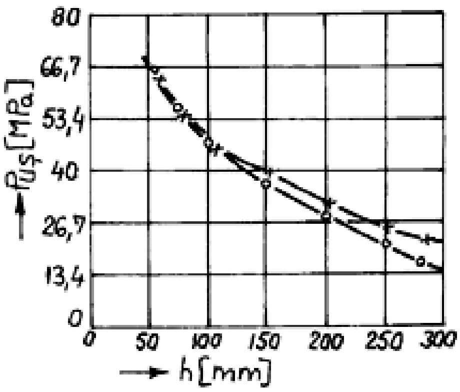

Fig. 5. The variation of shock wave pressure relative to discharge axis – plate distance.
U_0 = 36,4 kV; • I = 65 mm; ° I = 50 mm

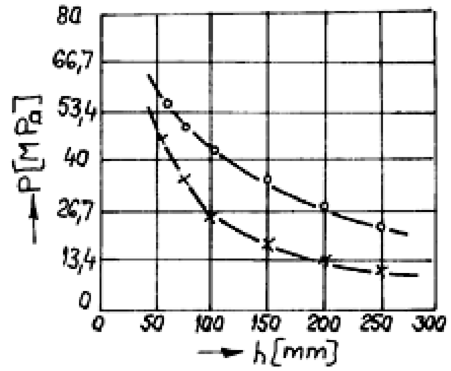

Fig. 6. The variation of shock wave pressure relative to discharge axis – plate distance.
I = 60 mm; U_0 = 33,2 kV; °shock wave; x gas bubble

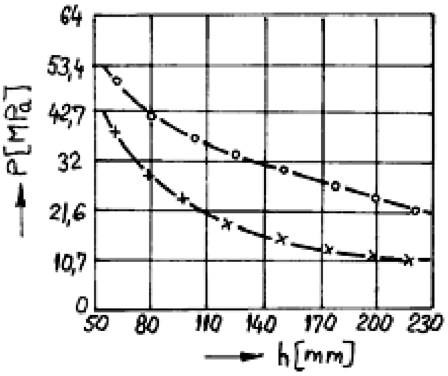

Fig. 7. The variation of shock wave pressure relative to discharge axis – plate distance.
I = 60 mm; U_0 = 28,4 kV; °shock wave; x gas bubble

3. THEORETICAL AND EXPERIMENTAL RESEARCHES FOR THE INFLUENCE OF ELECTRODE GEOMETRY

Electrohydraulic deformation is a complex process which involves a series of physico – mechanical phenomenons, by of which action, cumulative or individual, the shape of the plate is changed. In drawing's case, the plate is forced to copy the shape of cavity of mould on which it is placed.

The principal phenomenons involved in conversion of electrical energy (stored in condensers battery) in mechanical work for deformation are:

1. Formation of electro-conductor channel which closes the discharge space between electrodes;
2. Generation and propagation of shock wave through convection medium, as well as the interaction of shock wave with discharge chamber walls;
3. The interaction of shock wave front with the semi-manufactured plate;
4. The appearance of flux of cavitational and post-cavitational liquid and their action on the plate;
5. Deformation of semi-manufactured plate;
6. The appearance and the propagation of elastic and plastic stress waves in the warped material.

Each of these phenomenons is in an interlinked relation with the others, and leads to difficulties in the trial to find connection relations which allows not only the reproductibility of the process, but also his prediction.

The process of high development of discharge is preceded by the stage of formation of electro-conductor channel which short-circuit the space between electrodes. The most simple method is that of channel formation by direct high-voltage impulse breakdown of discharge space.

From the involved phenomenons point of view, the process can be presented as follows: when applying high voltage on discharge interval (between positive electrode, isolated on whole surface excepting his end, and negative electrode, in the same isolation conditions), it disruption occurs, being accompanied by the formation of electro-conductor channel, which starts with the formation of so called "lider" or of a series of growing liders. In fact, "lider" is a ionized channel, high self-luminous, with a diameter of 0,1…2 mm, surrounded by the diffusion luminiscence range. The appearance of "lider" development stage of the discharge is possible only after the current density reaches a certain critical value. The "lider" stage is over when one or more such liders (primers) touches the opposite electrode, generating the short-circuit bridge in the discharge space. So, the discharge channel is now realized. The intensity of electric field depends on the discharge space geometry, that is the shape of each of two electrodes.

The study of the disruption of the non-degased conductor liquids proved that even liders formation is preceded by another stage, so called "pre-lider" or "local stage – point-crest" (which later on will be replaced by the lider stage), when primers growing speed has a maximal value. The dynamics of primers system growing depends on the initial electrical parameters of the discharge circuit, shape of the space between electrodes, the conductibility of the medium, etc.

After short-circuit of the discharge space by the lider, starts the second stage (the main stage of discharge), when the electrical energy stored in condensers battery is almost entirely released. Under the action of the passage of the high density discharge current, as well as due to the liquid incompressibility, the pressure in discharge channel (channel obtained from the short-circuit of the electrodes by the lider) increases and can reach thousands of atmospheres. This increasing of the pressure can be explained if we consider the discharge space as a dense plasma with low temperature, in which the energy of electric field stored in the charged condensers is transformed in gas-kinetics energy of plasme particles movement.

Subsequent, due to high pressure and high speed expansion of discharge channel (under the action of gas-kinetics pressure), a shock wave occurs. Parameters of this shock wave are determined both by the processes developed in channel's plasma and by the hydrodynamic environment. When this phenomenon is studied, it must be taken into account even the interconnections between the processes which takes place at the border between those two mediums, using non-linear hydrodynamics and acoustic laws.

Simultaneous with shock-wave formation, the expanding channel of the discharge leads to movement of the surrounding liquid, realizing so called "delay flux", which at his turn, leads to the development of a gas bubble. This phenomenon can lead to a second pressure impulse, with a lower intensity in comparison with that on shock wave front. Cross corelation between these two impulses must be also taking into account.

As it was previously mentioned, in the case of the discharge with direct impulse breakdown of the liquid space, the processes which appears in the "pre-lider" stage has a great influence on the further development of the discharge channel and, in an implicit way, on the size of the pressure obtained in the discharge chamber. These processes establishes the delay time of the disruption, the power loss, the length of discharge channel, the initial diameter and the resistance of the channel. One of the most important factors which acts in this stage is the geometry of the electrode system.

In order to establish this influence, for identical variation domains of the discharge parameters, it has been used electrodes made from different materials and having different shapes and dimensions. The main characteristics of the used electrodes are distinguished in table 1 (C–conical; S–spherical; P–planar) and fig.8.

Table 1. Types of electrodes

Crest's shape	Diameter [mm]	Area [cm^2]	Material
C,S,P P	ϕ 6; ϕ 8; ϕ 10 ϕ 8	2,6 4,5	Cu
C,S,P	ϕ 6; ϕ 8; ϕ 10	2,6	Al
C,S,P	ϕ 6; ϕ 8; ϕ 10	2,6	Steel

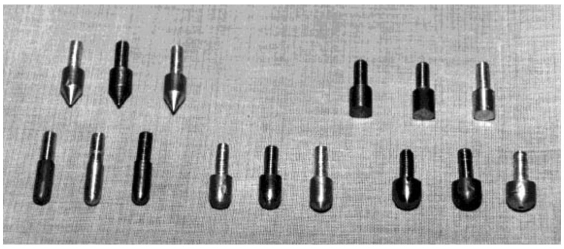

Fig. 8. Types of electrodes

The diagram of pressure variation reported to electrode gap, for Cu and steel, is presented in fig.9 (U_0 = 33,2 kV; h = 90 mm; conical crest, ϕ 8 mm • steel; ° Cu and Al; where U_o-discharge voltage of condensers battery through spark discharger, h-discharge axis-plate distance; l-electrode gap, P-shock wave front pressure).

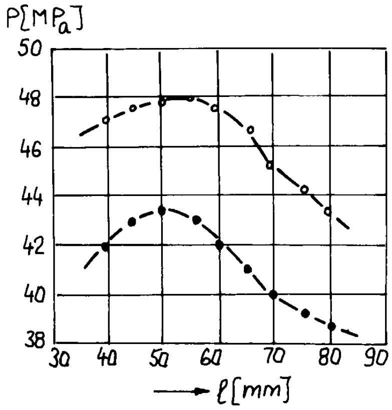

Fig. 9. Pressure variation reported to electrode material.

Because the values obtained for Al are not significant different from those obtained for Cu, the curve adequate to Al is not represented. The explanation for the difference between those two curves is given both by the different values of electrical conductibility of those two materials and by the manifestation of surface effect (on a side due to discharge current frequency in electrodes systems which, practical, is in the range 10…200 kHz [5], as a result of the vibrations of spark discharger plates and, on the other side, due to the modifications of the adequate current densities).

So, for a Cu bar, with a diameter ϕ 12 mm, to a current frequency *f = 200 kHz*, the calculated value of the ratio *R / l* is $R / l = 310 \cdot 10^{-5}\ \Omega / m$. The resistance of the same conductor in direct current is:

$$R = \rho \cdot \frac{l}{S} = 15{,}5 \cdot 10^{-5} \quad [\Omega] \qquad (1)$$

where ρ resistivity, $\rho = 0{,}0175\ \Omega \cdot mm$; **l** – conductor length ; **S**–cross section area of the conductor.

So, the resistance at a frequency equals with 200 kHz increases 20 times. For a steel bar with ϕ 12 mm, the value $R / l = 0{,}105\ \Omega / m$ is obtained, and the resistance in d.c. is R = 0,867· 10^{-3} Ω. As a result, for steel, the resistance increases 121 times. In the same time, for f = 200 kHz, the steel bar resistance increases about 34 times in comparison with Cu bar, and for d.c. increases with 5,6 times. The same considerations can be made for the materials used in construction of conductor rod as support for crests. Anyhow, the parts which directly conducts the energy to discharge space, is recommended to be realized by high conductor materials.

In fig. 10 has been ploted the variation of the pressure reported to the electrode gap, for three symmetrical geometries and one non-symetrical, the last one being accordingly to the case presented in fig. 11 (U_0 = 33,2 kV; h = 90 mm; Cu, ϕ 8 mm; ° conical crests; • semispherical; x planar; Δ adequate to case in fig.14). Decreasing of the obtained pressure is a result of the growing curvature radius of the electrode's crest (for those three considered symmetrical geometries), this phenomenon leading to a decreasing of the electric field intensity of the anode and therefore to higher power loss during the "pre-lider" stage. The results has been obtained using new electrodes at each experiment.

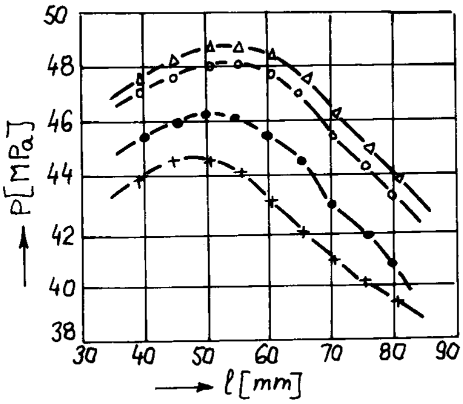

Fig. 10. The influence of discharge space geometry on pressure variation.

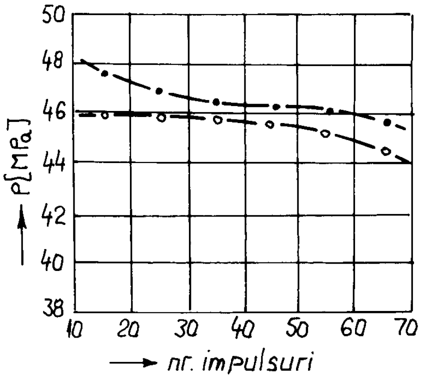

Fig. 12. Decreasing of pressure differencies at wear increasing.

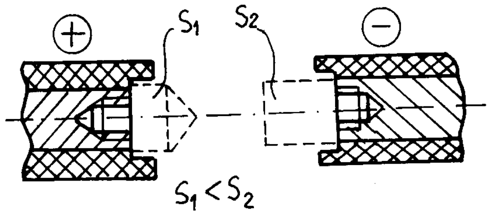

Fig. 11. The design of crest – plan geometry of electrodes system. ϕ 10 mm; S_1 = 2,6 cm^2; S_2 = 4,5 cm^2

When using new conical or semispherical electrodes occurs differencies regarding the pressure values, when the wear of the conical crests increases, the recorded values of the pressure are almost equal with those obtained in the caes of semispherical electrodes (fig.12; U_0=33,2 kV; h=90 mm; l=55 mm; Cu, ϕ 8 mm; • spherical; ° conical crest). This is because by wearing, the conical crest is transformed in semispherical.

The influence of electrode diameter on the mass of metal expeled at one discharge is taking into account by a coefficient, which doesn't depend on the electrode material. The values are given in [5], experimentally determined: for steel - 0,055; for Cu - 0,065; for brass - 0,06; for Al - 0,2.

4. THEORETICAL AND EXPERIMENTAL RESEARCHES FOR THE INFLUENCE OF EXPLODED WIRE GEOMETRY

In all cases, the exploding wires was made by copper. It is to be noticed from the beginning that, in comparison with the discharge with direct impulse breakdown, it doesn't automaticaly lead to an increasing of the shock wave pressure, but to a stabilization of the discharge. This fact increases both the reproductibility capacity and the prediction degree of the process. Near all these, the existence of the conductor bridge between electrodes eliminates the danger of arc-over, and this is the reason why the report value **h / l** can be decreased under the unity value (**h / l < 1**, where **h** - discharge axis - plate distance; **l** - electrode gap). This aspect is of a great importance, because is the only way to obtain pressures with the same values as in the case of the discharges with direct impulse breakdown of discharge space. As a general rule, for same experimental conditions, the pressure obtained by initiation is about 70 % from that obtained by direct stroke. The explanation stands in a higher power loss in the time before formation of the discharge channel, both for fusing and vaporization of the wire (sublimation).

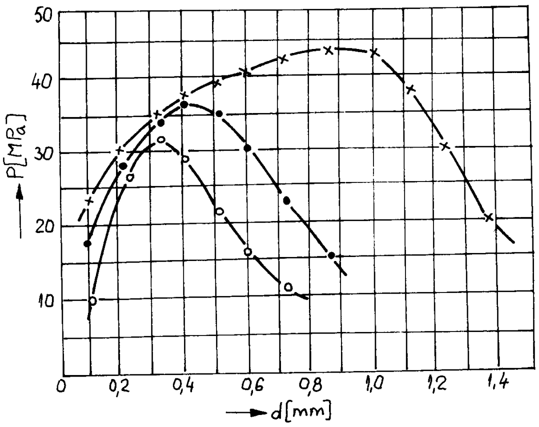

Fig. 13. The variation of pressure relative to the diameter of copper linear conductors.

In fig. 13 is presented the variation of pressure relative to the diameter of some linear copper conductors, for different charge voltages of condensers battery (l = 80 mm; h = 50 mm; • U_0 = 26,8 kV; ° U_0 = 23.3 kV; x U_0 = 35,6 kV).

From presented diagram results that the known principle of optimal wire diameter is also true in the high voltages domain, the optimal value of the diameter increasing when voltage or discharge energy increase. The evaluation of pressure maximal value can be made similar to direct impulse breakdown, taking into account [5] changing of spark characteristic value.

5. CONCLUSIONS

The experiments pointed out that, in a large measure, the rules from low voltages keeps their validity in the domain of high voltages, but for all that, some differences occurs. As can be observed in presented figures, the variation of pressure related to discharge voltage is quite quasilinear for the considered domain of voltages, although in certain conditions, it could differs from this rule. Thus, these deviations occurs for short electrod gaps and higher voltages ($l < 30$ *mm* and $U_0 > 30$ *kV*), because the discharge is approaching to the short-circuit regime, and also in the long electrode gaps domain and lower voltages ($l > 80$ *mm* şi $U_0 < 25$ *kV*), due to high dissipation of energy in the “pre-lider” stage (spark development). From this reason, the calculus relations for the pressure presented in paper [2] must be carefully applied, being necessary to identify the causes of differences bigger than those given by the recommended correction coefficient.

Regarding to the dependence in fig. 3, it is to be noticed that, when the capacity is modified than, in an implicit way, is also modified the discharge circuit inductance, due to the modification of that component linked by the own inductances of the condensers. Anyway, for the chosen values domain of capacity, the pressure dissipation due to capacity decreasing prevails on the pressure rise due to decreases of discharge circuit global inductance.

For the variation of pressure related to the discharge axis – plate distance *h*, presented in figures, it is to be noticed a higher influence of voltage modification in comparision with the influence of electrode gap, on the pressure in shock wave. The influence of electrode gap is much stronger at long *h* distances, due to the modification of shock wave front shape and to a quick attenuation of pressure at lower values of electrode gap *l*. Related to this last aspect, it is to be noticed the nature modification of the electrode gap influence in the case of high voltages, reported to the nature presented in the case of relative low voltages - where the pressure follows more quickly the modification of this parameter. Also, it is to be noticed the quasilinear variation of pressure on shock wave front, for values $h / l = 1 \ldots 2$, this leading to the conclusion that, in the values combinations domain of electrical and geometrical parameters, interesting from the maximum technological effect point of view, is possible to find some polynomial mathematical models in order to predict the values for pressure, maximum drawing depth and drawing part shape.

Concerning the electrodes' geometry, it is to be noticed the behaviour in the case of non-symmetrical configuration as shown in fig.14, where using a conical and a planar electrode (the last one having the same diameter but a greater wetted surface), an easy increasing of pressure has been obtained. Not the same thing was obtained when reversing the electrodes polarity. This can leads to the conclusion that, in the case of the discharge with high voltage direct impulse breakdown of the space between electrodes, the area of negative electrode has a great importance. Increasing of cathode area in comparison with that of the anode can lead to pressure increasing. But for the anode, when it's wetted surface increases over 5 cm^2, can occur an important pressure loss.

In conclusion, when choosing the configuration of the discharge space in the case of direct impulse breakdown of the liquid space, is necessary to be taken into account elements linked both by the maximum technological effect (or by wearing resistance) and by safety in use or by electrodes systems cost.

Taking into account all we said above, results that the electrohydroimpulses drawing requires to know and to control a large number of independent processes, on these processes acting the influences of a lots of factors. Even if the papers which treats this proceeding are not quite a few, its doesn't succeed to offer valid and truth-like indications on the concrete model of the process development, indications which could allows to prescribe technological recommendations with universal validity.

As a new research direction, obtaining by electrohydroimpulses in monoimpulse regime of the conical parts is more propitius from the part quality and accurate point of view, but it is advisable to be limited to the conical parts with flange, with apex angles over 60° and with small apex filleted radius. In the case of the parts with high drawing depths, manufacturing using just one impulse is obviously insufficient. In this case it is to be used multiimpulse drawing, shot by shot regime or automatic regime (impulse sequence or spike train). It is expected that, due to wrinkling tendency and material hardening, as well as due to the increasing of plate – discharge axis distance, the deformation of the plate to be more harder that on primary impulse. The technological implications of multiimpulse manufacturing can be the subject of subsequent researches in the field.

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