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CONSIDERATIONS ON THE SHAPE OF DISCHARGING CHAMBERS FOR THE ELECTRO-HYDRAULIC DEFORMING METHOD

Abstract: *The electro-hydraulic plastic deforming method belongs to non-conventional plastic deforming techniques class. The shape of the discharging chamber and of the energy concentrators influences workpiece machining, along with the other parameters of the equipment (electrical pulses, electrodes, space between electrodes, pressure wave transmission medium, way to propagate the pressure wave). The paper proposes a comparative analysis of the geometric parameters of the discharging chambers and of their effects on the technological processing.*

Key words: *chamber shape, energy concentrator, cylinder, cone, parabola, exponential profile.*

1. INTRODUCTION

The plastic deforming method with electro-hydraulic impulses belongs to high power and speed deforming techniques class.

The processing principle is based on the deformation of the workpiece under the successive action of the shock wave and of the cavitational and post-cavitational liquid flows coming out the electric discharge in liquid medium. In fact the procedure technologically capitalizes a wide range of physical phenomena: electric discharge in liquid medium (clear or by wire activation), shock waves occurrence and propagation in liquid medium, interaction of the shock waves with the walls of the discharging chamber and with the workpiece to be processed, formation and action of the cavitational void followed by post-cavitational liquid flow. Therefore, conversion process of the electric energy stored in capacitor bank into plastic deformation energy is a complex phenomenon influenced by a great variety of factors and parameters [4].

Electro-hydraulic deforming method is world wide applied in nowadays in vehicle construction industry, arms industry, aviation industry, electro technique etc.; the method continues to focus specialists' attention in order to extend the range of potentially processed items.

Electro-hydraulic impulses machining is efficiently applied particularly to tubular parts and metal sheet parts of complex shape, large scale, made of materials with enhanced physical-chemical properties for which conventional manufacturing processes are practically impossible to be applied [1].

Compared to classic deforming techniques the electro-hydraulic deforming method offers significant advantages: efficient use of energy, strict control of technological parameters, possibility to create overpressure in working environment, possibility of process automation, low risk, substantial decrease of equipment cost, increased geometric and dimensional accuracy along with part's surface quality. Moreover, the electro-hydraulic deforming technique contributes to improve the design solutions of parts, with consequences on reducing technological consumption and improving reliability [2].

2. STRUCTURAL COMPONENTS OF ELECTRO-HYDRAULIC EQUIPMENT

The fundamental structure of the electro-hydraulic plastic deforming equipment consists of three main components [3]:

- pulse generator;
- discharging chamber;
- command system.

The pulse generator settles the deforming operating parameters and it consists of two circuits (the charging circuit and the discharging circuit) having the capacitor bank as common element.

The discharging chamber represents the place the electric energy is converted into deformation mechanical work. Inside the discharging chamber are placed the electrodes immersed in liquid medium. The liquid represents the shock wave energy and the liquid flow propagation medium. The energy converted into mechanical work causes the deformation of the workpiece on the mould.

The command system ensures operating the pulse generator and the discharging chamber and connects the two parts of the equipment.

The paper work proposes a study on the shape of the discharging chamber as one of the defining elements of the electro-hydraulic deforming technological system.

The geometry of the discharging chamber has an important influence on the conversion of the electric energy into mechanical work.

The shape of the discharging chamber is essential to the optimization of the processing technology. As a result of the interaction of the shock waves with the discharging chamber, the distribution of the pressure field on the workpiece is both qualitatively and quantitatively modified. The shape and the dimensions of the discharging chamber can change the emergence of cavitation phenomenon and can modify the quantum of energy transferred to the workpiece as compared to the energy emitted by the shock wave and the reflected waves [3].

Electric discharge in liquid medium is followed by an intense cavitation phenomenon. The cavitation, caused by a rupture in liquid continuity due to dilatation forces, is materialized by emerging a great number of small vapor bubbles, set in motion by the strong liquid pulses [5].

In terms of size the discharging chambers are classified as large and small. The large chambers are the ones the cavitation occurs. The small chambers are the ones with the volume comparable to gas cavity's volume; therefore the cavitation does not occur.

Electro-hydraulic deforming method is specified by a great variety of parameters. The main parameters related to the geometry of the discharging chamber are [3]:

- coefficient k_{1f} – it specifies the joint actions of cavitational and post-cavitational liquid flows; the coefficient is the expression of quantitative evaluation of the conversion process of shock waves energy into energy transferred to workpiece:

$$k_{1f} = \frac{Wcf + Wpf}{Wdirt} \qquad (1)$$

W_{cf} – energy of cavitational flow
W_{pf} – energy of post-cavitational flow
W_{dirt} – energy of shock wave at time t

- volume of the discharging chamber – V;
- relative inertia of the workpiece – β (it's value is usually 1÷5);
- ratio between displacement resistance force of the workpiece (F_0) and maximum power of the shock wave (P_{max}) – F_0/P_{max}.

3. GEOMETRIC PARAMETERS OF LARGE VOLUME DISCHARGING CHAMBERS FOR PLANE WORKPIECE

3.1 Cylindrical discharging chamber

Cylindrical discharging chamber (Figure 1) is widespread as its geometry is a simple one. The volume of the chamber can be changed modifying dimension h_2. The result of lengthening dimension h_2 is increasing the time the cavitation occurs and reducing the value of coefficient k_{1f}.

Point O is the midpoint between the electrodes, points A, B, C represent the points the reflected waves hit the discharging chamber; α_1, α_2, α_3 represent the angles between the reflected waves and (OY) axis; β is the angle between the incident wave and (OY) axis.

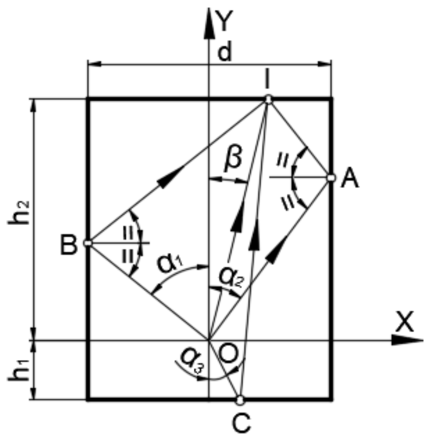

Figure 1 Cylindrical discharging chamber.

3.2 Cylindrical discharging chamber with ring–shaped pressure concentrator

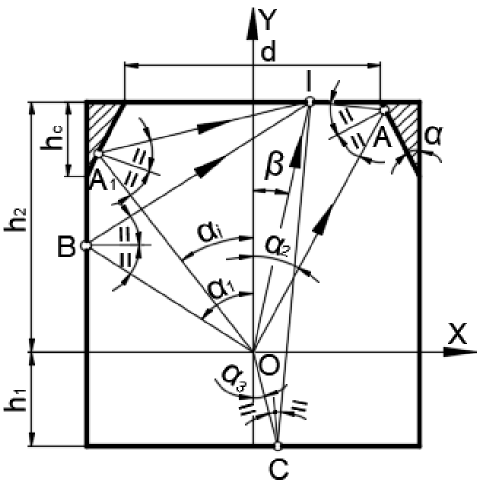

Figure 2 Cylindrical discharging chamber with ring–shaped pressure concentrator.

A variant of cylindrical discharging chamber is the one equipped with ring–shaped pressure concentrator (Figure 2). The cross-section of the concentrator is specified by two dimensions: the height (h_c) of the concentrator and the rake angle (α) of cone's generating line.

Pressure distribution field for this construction type discharging chamber is non-uniform comparatively to the variant without concentrator, but the pressure value is higher. In this case an increase is obtained in transferring the pressure impulse to the workpiece by liquid medium.

Point O and the other dimensions marked in Figure 2 have the same meaning as previously explained in paragraph 3.1; α_i is the angle between the wave reflected by the concentrator and (OY) axis.

3.3 Conical discharging chamber

The geometry of conical discharging chamber (Figure 3) is specified by dimensions h_3 and d_1. The volume of the discharging chamber can be changed modifying dimension h_3.

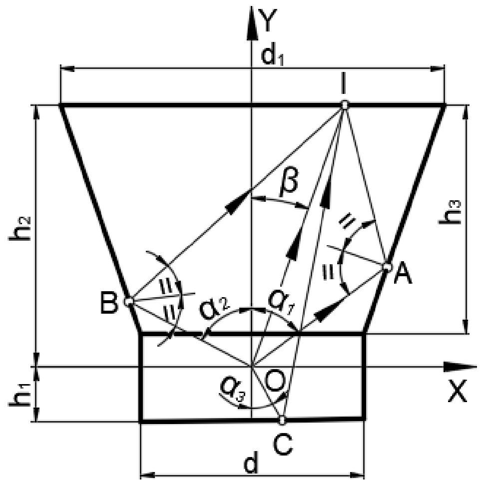

Figure 3 Conical discharging chamber.

If the heights ratio (h_2/h_3) has a constant value the dimension h_3 has no influence on the time the cavitation occurs.

The result of lengthening dimension h_3 is increasing the time the cavitation occurs and strongly reducing the value of coefficient k_{1f}, similar to the case of cylindrical discharging chamber.

The pressure distribution on the surface of workpiece is characterized by a higher uniformity, due to intense dispersion of the reflected waves on the lateral surface of the cone.

Point O and the other dimensions marked in Figure 3 have the same meaning as explained in paragraph 3.1.

3.4 Parabolic discharging chamber

The discharging chamber with parabolic profile (Figure 4) is harder to be manufactured from technological point of view. Point O (the midpoint between the electrodes) must be located on the focus point of the parabolic profile.

The reliance of time the cavitation occurs and of coefficient k_{1f} on the dimension h_2 are similar to the case of cylindrical and conical discharging chambers.

The specificity of parabolic discharging chamber is a higher uniformity of the pressure distribution on the surface of the workpiece compared to the conical discharging chamber.

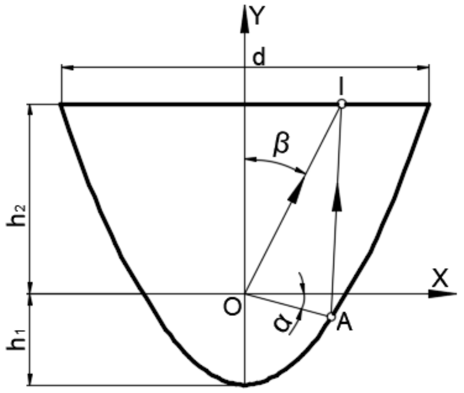

Figure 4 Parabolic discharging chamber.

3.5 Parabolic discharging chamber with pressure concentrator

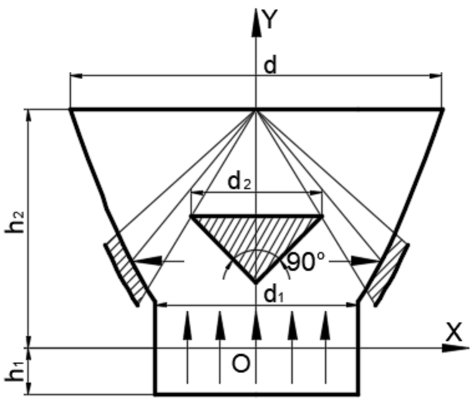

Figure 5 Parabolic discharging chamber with pressure concentrator.

The parabolic discharging chamber may be equipped with a pressure concentrator (Figure 5). This discharging chamber version is advised to be used when concentrating the energy of the shock wave and of the pressure distribution is need on a small area. The pressure concentrator is an ultrasonic one.

This constructive solution is of practical interest when the electro-hydraulic effect is generated by wire activation, in which case the symmetry of the shock waves is a cylindrical one. Analyzing the pressure distribution on the workpiece there is a strong focus of pressure on indicated area (Figure 5), where a higher density of energy transferred to workpiece is noticed.

3.6 Discharging chamber with exponential profile

The discharging chamber with exponential profile (Figure 6) is recommended when obtaining high energy concentrations in a limited volume is necessary. The shape of the discharging chamber was suggested by the use of exponential profile concentrators in ultrasound processing; the form of the cross section variance is [4]:

$$S_h = S_0\, e^{-mh} \qquad (2)$$

m = constant specifying the variance of the cross section across discharging chamber.

Increasing trend of time the cavitation occurs is also expressed when discharging chamber’s volume expands. The pressure distribution indicates higher values of pressure compared to the other analyzed discharging chambers.

It is observed when using this type of discharging chamber that the cumulated action of the incident shock waves and the waves reflected by chamber walls is more intense.

The phenomenon is explained by the property to concentrate the pressure waves reflected by the walls provided by chamber profile. The consequence of this is increasing the time the cavitation occurs.

Due to the great amount of energy transferred to workpiece the values of coefficient k_{1f} are higher compared to previously analyzed discharging chambers.

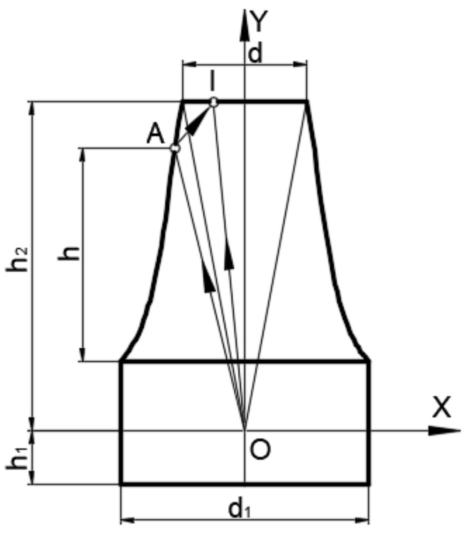

Figure 6 Discharging chamber with exponential profile.

4. GEOMETRIC PARAMETERS OF SMALL VOLUME DISCHARGING CHAMBERS FOR PLANE WORKPIECE

The main characteristic of small volume discharging chambers is that the cavitation phenomenon does not occur, as chamber's volume is comparable to the volume of gas cavity.

Based on the previous considerations, the action of the shock waves was limited by the time the pressure of gas cavity starts the process of charging the workpiece.

Small volume discharging chambers have the same geometrical characteristics as the large volume discharging chambers presented in paragraph 4; the study of the parabolic discharging chamber was removed because at a small volume its parameters are similar to the parameters of the conical discharging chamber.

For small volume discharging chambers was found that the values of the useful action of shock waves coefficient k_{1f} are not influenced by the geometry of the chamber. Due to the limited volume of the chamber coefficient k_{1f} has a slight increasing tendency, but it is not qualitatively different compared to large volume chambers [3].

Geometric parameters of the discharging chambers have significant influence on the pressure distribution on the surface of the workpiece. Compared to large volume discharging chambers for the small volume ones the pressure distribution is more uniform. This is explained by the fact that the journey of the reflected waves is much shorter and shock waves' duration of action is also shorter.

5. GEOMETRIC PARAMETERS OF DISCHARGING CHAMBERS FOR TUBULAR WORKPIECE

Electro-hydraulic deforming process for tubular parts has a number of specificities mainly required by the shape of discharging chamber, determined by the tubular workpiece to a greater extent than in case of plane workpiece. As the workpiece is tubular the discharging chamber originally has the same geometric shape in absence of pressure concentrators. In this case the discharging chamber may consist of the tube itself. Waves' lateral walls reflection process is supplemented by the reflection at the ends of the tube [3].

The discharging chambers for tubular workpiece are usually equipped with pressure concentrators having different shapes and locations as follows:

- discharging chamber equipped with two pressure concentrators with exponential profile (Figure 7);
- discharging chamber equipped with two conical pressure concentrators (Figure 8);
- discharging chamber equipped with one conical pressure concentrator (Figure 9).

Point O is the midpoint between the electrodes; α_1 is the angle between the incident wave and the wave reflected by the concentrators; α_2, α_3 represent the angles between the reflected waves and (OY) axis.

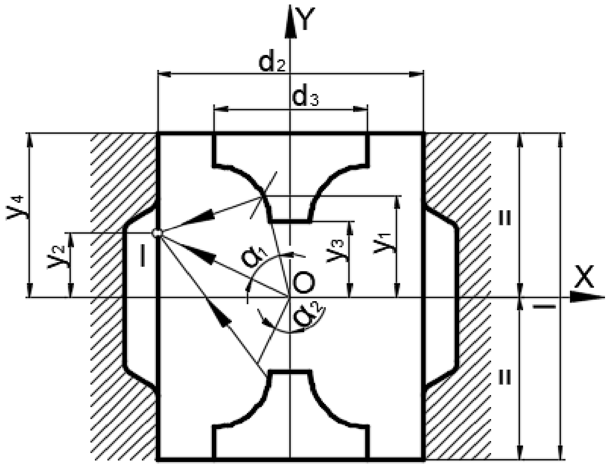

Figure 7 Discharging chamber equipped with two pressure concentrators with exponential profile.

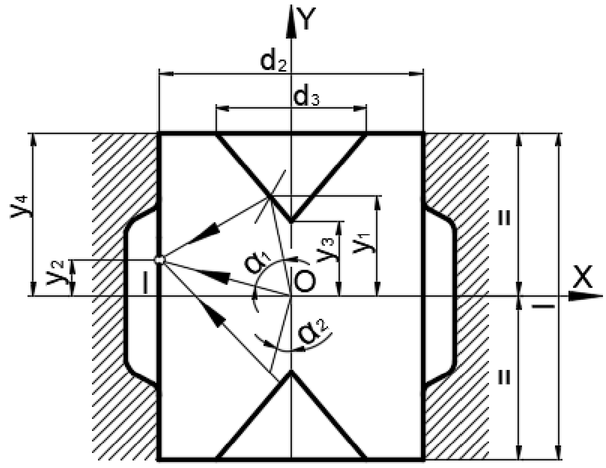

Figure 8 Discharging chamber equipped with two conical pressure concentrators.

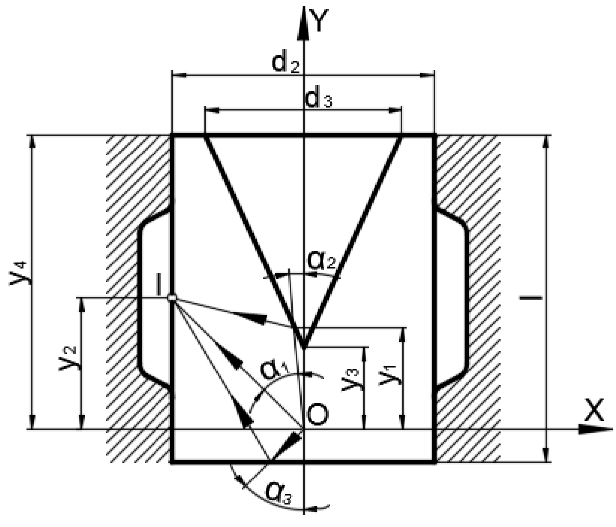

Figure 9 Discharging chamber equipped with one conical pressure concentrator.

Practice proves that for coefficient k_{1f}, measuring the useful action of shock waves, are not recorded substantial differences between the three analyzed discharging chambers (Figure 7, Figure 8, Figure 9); the values of the coefficient are not influenced by the shape of the pressure concentrators [1].

For the time cavitation occur as well as for coefficient k_{1f} come out relatively significant differences between the discharging chamber consisting of the tube itself and the discharging chambers equipped with pressure concentrators. When using the pressure concentrators the values of the mentioned parameters are significantly improved.

The pressure distribution field on the surface of the tubular workpiece indicates that maximum pressure values are 25% higher for discharging chambers equipped with concentrators compared to discharging chambers without concentrators [3].

Important qualitative differences come out between the discharging chambers equipped with two concentrators and the ones equipped with one concentrator.

Thus, for discharging chambers equipped with two concentrators the pressure distribution is uniform unlike the pronounced non-uniformity of the pressure distribution for discharging chamber with a single concentrator. This aspect emphasizes the possibility to direct the pressure distribution on the surface of workpiece related to the final geometric characteristics of the part.

The tubular discharging chambers were not analyzed in terms of size because practice proves that there are no significant differences between large volume and small volume discharging chambers regarding the values of coefficient k_{1f}. In both cases (large and small volume chambers) the efficiency of shock waves action is not influenced by concentrators' geometry [4].

6. CONCLUSIONS

Electro-hydraulic deforming is based on high voltage electric discharge followed by a shock wave propagated in the liquid medium it occurs. The pressures coming out this complex process are transferred through the liquid and they cause plastic deforming of the workpiece inside discharging chamber.

One of the most important physical phenomenon occurring during electro-hydraulic deforming is cavitation. Thus, the workpiece is under the influence of the liquid flows that precede and follow cavitation. The conjoint action of cavitational and post-cavitational liquid flows deforms the workpiece, regardless of the shape and volume of discharging chamber [4].

The influence of geometric parameters of the discharging chamber, of parameters and nature of the liquid medium on the reliability of the complex process during the action phases of the cavitational and post-cavitational liquid flows were studied both in engineering practice and with the help of an application. Both methods led to similar results allowing drawing graphs showing the dependence of coefficient k_{1f} (efficiency of

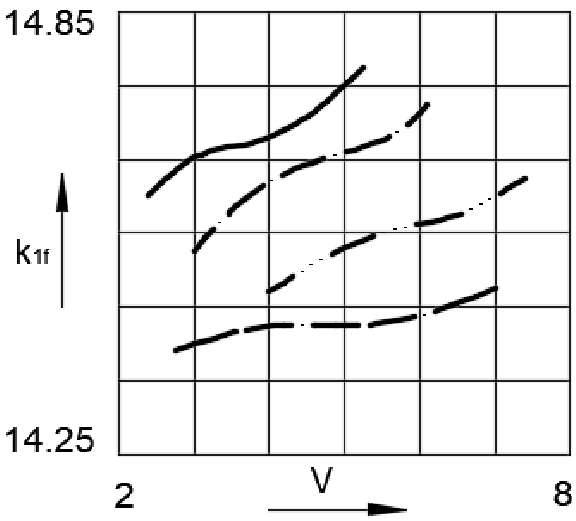

Figure 10 Dependence of coefficient k_{1f} on the volume of the discharging chamber.

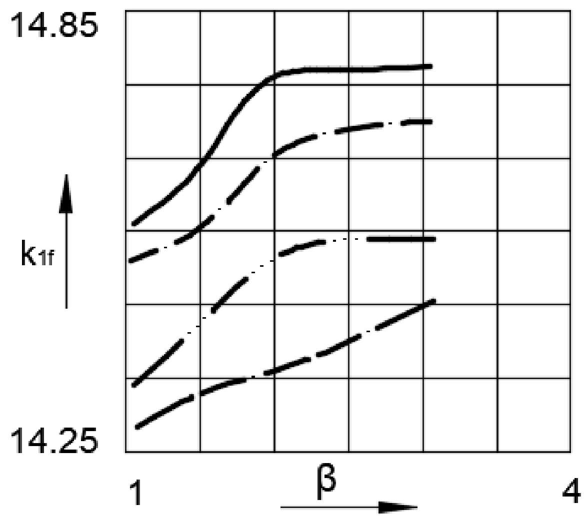

Figure 11 Dependence of coefficient k_{1f} on the relative inertia of the workpiece.

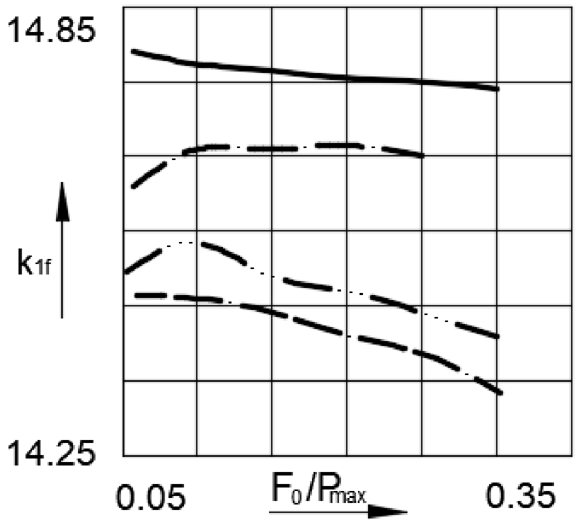

Figure 12 Dependence of coefficient k_{1f} on the ratio F_0/P_{max}.

shock wave action) on geometric parameters and shape of the discharging chamber (Figure 10), on the relative inertia of the workpiece (β) (Figure 11) and on the ratio between displacement resistance force of the workpiece and maximum power of the shock wave (F_0/P_{max}) (Figure 12).

The three graphs were drawn for four representative discharging chambers:

- parabolic discharging chamber (solid line);
- conical discharging chamber (dash dot line);
- cylindrical discharging chamber (dash triple dot line);
- discharging chamber with exponential profile (double dash dot line).

The graphic dependence of the energy ratio (coefficient k_{1f}) on the volume of the discharging chamber (Figure 10) proves that as chamber's volume increases the efficiency of the process increases too. The explanation of the phenomenon is that as chamber's volume increases the shock waves' energy transferred to workpiece is diminished.

The graphic dependence of coefficient k_{1f} on the relative inertia of the workpiece (Figure 11) proves that the coefficient increases as the inertia increases.

The graphic dependence of coefficient k_{1f} on the ratio F_0/P_{max} (Figure 12) proves a relatively pronounced trend on decreasing of coefficient as the ratio increases. The explanation of the phenomenon is that within the timeframe the shock waves are working, the workpiece receives a high quantum of energy of all energy of shock waves at the same time with the increase of ratio F_0/P_{max}.

The graphs prove that ratio F_0/P_{max} (effective action of shock waves) is highest for discharging chamber with exponential profile, followed by the cylindrical discharging chamber equipped with one pressure concentrator. This is due to focusing the reflected shock waves by the surface of the workpiece [5].

The graphs also prove that coefficient k_{1f} (joint actions of cavitational and post-cavitational liquid flows) has the highest values for parabolic and conical discharging chambers. This may be explained by achieving maximum energy due to increase the amount of fluid striking the workpiece.

Theoretical and practical approach on electro-hydraulic deforming method proves that the action of the shock waves on the workpiece is common both to the process developed on large volume discharging chambers and on small volume discharging chambers [3], [6].

The action of the gas cavity over the workpiece is decisive for the efficiency of the deforming process in small volume discharging chambers.

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