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# USING OF MECHANOTRONICS DEVICES FOR WORKING MOVEMENTS WORKPIECES DURING WATERJET CUTTING

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**Abstract**

*Consider the use of mechatronic systems in the drive supply jetting equipment.It is shown that the creation of prestress due to such a drive in the cutting area significantly improves performance in jet cutting process to 25-35%.The optimum thickness of the blanks in which the use of pre-loading is energetically feasible.The dependence of the efficiency and the angle of the direction of the tangent to the stress created trajectory move ink jet head.*

**Keywords:** mechanotronics devices; contour cutting; stressed state.

## INTRODUCTION

In modern engineering increasing distribution is received by different mechatronic systems that improve the quality of controlled workflows, reduce the number of information channels, increase the flexibility of the system as a whole.

Using the mechatronic systems in working drives of technological equipment also makes it possible to escape from the rigid framework of regulation and solve problems that in the traditional representation require a plurality of auxiliary devices, tools and information flows.

Creating certain conditions for the occurrence of workflow is one of the ways of increasing the efficiency of the processing of materials by cutting. It is known that for waterjet cutting the production of new interfaces is intensified with creation of the state of stress in the surface layer and the cross section of treated workpiece [1]. The author [2] proposes to divide labor movements on shaping and intensify. However, as the technical solutions for the realization of the idea of movements separation are quite complex and energy-intensive, search of rational schemes and methods of implementation of processing is important and relevant scientific and technical task that makes it possible to significantly improve the energy efficiency of waterjet cutting of sheet materials.

The appearance of mechatronics systems and reducing mass and dimension parameters of the drive leads to the fact that the mechatronics systems can be the basis for the creation of adaptive drive systems of displacement.

The aim of this study is to evaluate the possibility of increasing the effectiveness of contour cutting through the introduction of additional means of working load in the form of microdrives system, working in the field of elastic deformations of the elastic compensating elements of gripping devices.

## THE MATTER OF RESEARCH

It was suggested [1,3] that treatment can be improve by increasing the stress state in the cutting zone, for instance by creating tensile stresses in a direction perpendicular to the movement of the work feed. However, for contour cutting with arbitrary inkjet head movement problem has not been solved, since the movement of the inkjet head is performed under constantly changing angles relative to the main axes of the drive.

When using the drive with elastic elements for the waterjet cutting machine of layout decision represented in Figure 1 (with retention of workpiece with tick gripping elements in the linkage system of displacement), the creation of stress state in the sheet blank is possible using: 1) drives of longitudinal movement along OX (Figure 2 a), wherein in the elastic range of the cutting zone is formed the tensile stress; 2) drives of rotary motion relative to OZ at points of capture, using which tensile stresses are formed in a remote area in the direction OY, and in places of tongs - compressive; 3) simultaneous use of the rotary and longitudinal movements drives, which makes it possible to change the position of the most loaded zone along OY.

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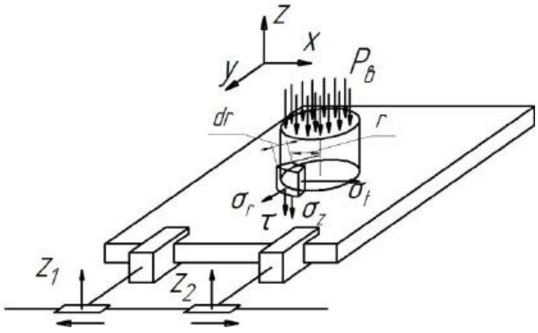
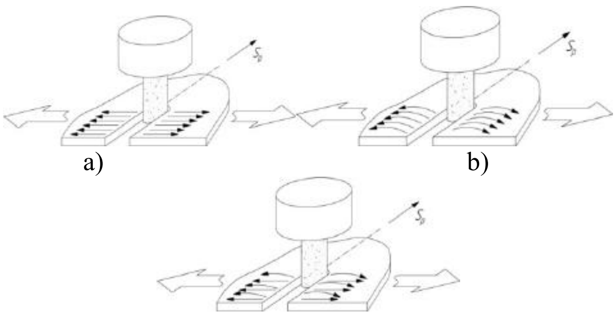



*Fig. 1. The layout of waterjet cutting machine with a movable workpiece and movable jet head in a vertical plane (fixed in the plane XOY)*

It is envisaged that in the places of engagement with contact patch *b*x*h* is possible to install auxiliary drives, providing pre-loading of the workpiece in the cutting zone with tensile strength, which appears due the linear micro-movement along the OX-axis, as well as forces arising due to the rotation around the vertical axis OZ, i.e. making movement $c_1$ and $c_2$.



a) b)

c)

*Fig. 2. Creation of stress state of the workpiece in the cutting zone with longitudinal loading by force R (a) and loading momentum M relative to OZ (b), the combined action of the force and momentum (c)*

Thus, there are three ways to create a stress state in the cutting zone (Fig. 3): tensile from the longitudinal movement of the grippers (Fig. 3a), from turning the grippers around axis $z_1$ and $z_2$ (Fig. 3b), as well as from their simultaneous action (Fig. 3c), which makes it possible to modify the shape of loading diagrams, redistribute compressive and tensile stresses in the layer of workpiece relative to the **XYZ** coordinates.

The tension in the microscopic volumes of workpiece at the point of jet leakage is determined by the known [4] ratio established for the area *ds*, angled *αt* relative to the main axes:

$$\sigma_a = \sigma_1 \cdot \cos^2 \alpha_1 + \sigma_2 \cdot \cos^2 \alpha_2 + \sigma_3 \cdot \cos^2 \alpha_3 \quad (1)$$

$$\tau_a = \sqrt{\sigma_1^2 \cdot \cos^2 \alpha_1 + \sigma_2 \cdot \cos^2 \alpha_2 + \sigma_3 \cdot \cos^2 \alpha_3 - \sigma_\alpha^2} \quad (2)$$

At the same time, for the vertical arrangement of the axis OZ and the case of load symmetry we have:

$$\sigma_a = \sigma_n \cdot \left(\cos^2 \alpha_1 + \cos^2 \alpha_2\right) + \sigma_3 \cdot \cos^2 \alpha_3 \quad (3)$$

$$\tau_a = \sqrt{\sigma_n^2 \cdot \left(\cos^2 \alpha_1 + \cos^2 \alpha_2\right) + \sigma_3^2 \cdot \cos^2 \alpha_3 - \sigma_\alpha^2} \quad (4)$$

where $\alpha_1$, $\alpha_2$, $\alpha_3$ – the angles formed with the site normal with the direction of force action of the drives R and the jet;

$\sigma_1, \sigma_2$ – stresses due to microdisplacements drive installed in the gripper mechanism.

Orientation of area is caused by the direction of movement of the working feed and waterjet cutting front position; thus, the drive must provide such state of stress in the cutting zone, which intensifies the process in the required direction only. Typically, this is the direction perpendicular to the tangent to the contour of cutting.

Jet action on a dedicated micro-volume of surface is defined as:

$$\begin{cases} \sigma_r = 2G \cdot \left( \dfrac{du}{dr} + \dfrac{\nu\varepsilon}{1-2\nu} \right) \\ \sigma_t = 2G \cdot \left( \dfrac{u}{r} + \dfrac{\nu\varepsilon}{1-2\nu} \right) \\ \sigma_z = 2G \cdot \left( \dfrac{dH}{dz} + \dfrac{\nu\varepsilon}{1-2\nu} \right) \\ \tau = 2G \cdot \left( \dfrac{dH}{dz} + \dfrac{dH}{dr} \right) \end{cases} \quad (5)$$

where $\frac{du}{dr} = \varepsilon_r$ – radial deformation;

$\frac{dH}{dz} = \varepsilon_z$ – axial deformation;

$\frac{u}{r} = \varepsilon_t$ – tangential deformation;

Then the equilibrium conditions of the selected item will be the following:

$$\begin{cases} \dfrac{d\sigma_r}{dr} + \dfrac{\sigma_r - \sigma_t}{r} + \dfrac{d\tau}{dz} = 0 \\ \dfrac{d\sigma_z}{dz} + \dfrac{d\tau}{dr} + \dfrac{\tau}{r} = 0 \end{cases} \quad (6)$$

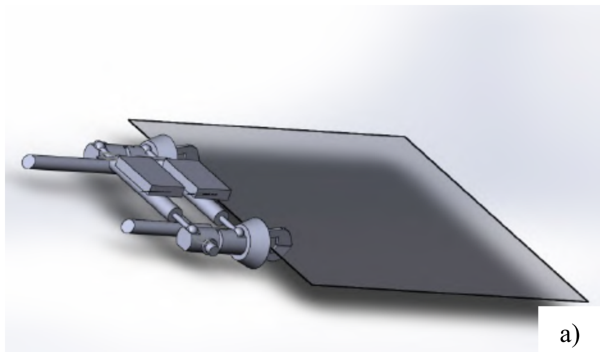
And differential equations of motion in vertical and horizontal directions *U* and *H* can be written as follows:

$$\begin{cases} (1-2\nu) \cdot \left( \Delta U - \dfrac{U}{r^2} \right) + \dfrac{d\varepsilon}{dr} = 0 \\ (1-2\nu) \cdot \Delta H + \dfrac{d\varepsilon}{dz^2} = 0 \end{cases} \quad (7)$$

$$\Delta = \frac{d^2}{dr^2} + \frac{d}{rdr} + \frac{d^2}{dr^2}$$

The simultaneous action of the jet and the tensile stress in the thin plate - workpiece - causes a complex stress-strain state of the workpiece with the movements *U* and *H*. Movement *U* ultimately will determine the accuracy of the cut contour.

Implementation of simulation experiments required the creation of computational model of special grippers for the loading and traversing of sheet blanks *B*x*L* size with the supplementary mechanotronics microdisplacement drives (Fig. 3a), which allows to present the cutting zone scheme in accordance with Fig. 3b.



a)

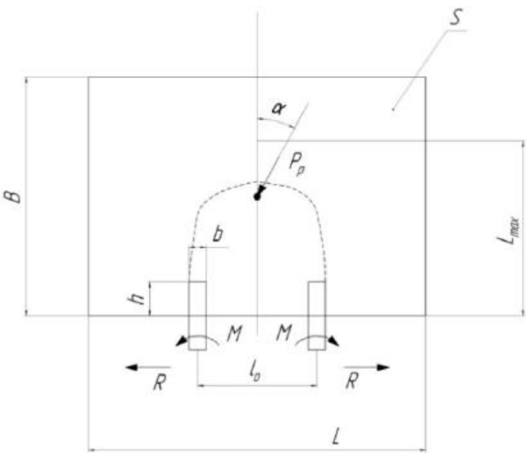


Fig. 3. Captures with microdisplacements drives (a) and the calculation scheme of sheet blank with preload area (b)

To solve this problem it have been taken into account the following parameters of the process:

- external forces generated by the drive: the power R and the momentum M;
- load $P_p$, and the angle α of the liquid jet load;
- geometric parameters of the capture, the distance between the tongs $l_0$; width $b$ and length $h$ of capture zone.

To estimate the rate of material removal under condition of creation additional loading of cutting area use empirical formula presented in [2]:

$$Q = 0{,}106 \cdot \left(\frac{P}{100}\right)^{2,4} \cdot d_c^{-0,27} \cdot h^{-0,35} \cdot \left(\frac{\sigma'}{100}\right)^{-0,75} \qquad (8)$$

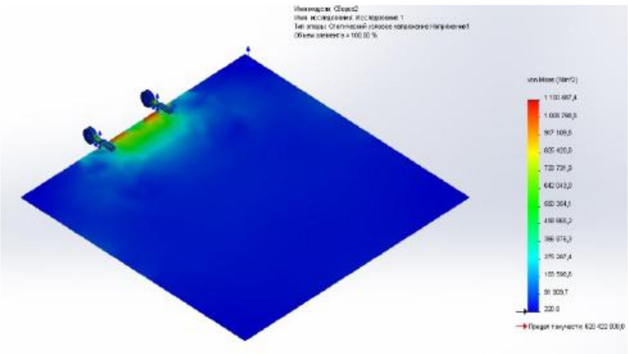
where $P$ – pressure in hydraulic, MPa;

$d_c$ – inkjet nozzle diameter, mm;

$h$ – processed material thickness, mm;

$\sigma'$ – reserve strength of the material as the difference $\sigma_p - \sigma_H$, where $\sigma_H$ stress generated by the supply drive. Such assumptions are possible on the basis of the result of analysis [5], but the magnitude $\sigma_H$ will depend on the position of the destruction platform at the front of waterjet cutting and movement direction of inkjet head relative to the axis of symmetry of additional created load.

Next, it was determined the sizes of the zone of stress-strain state of the workpiece and the maximum stress arising out of contact with the tongs (Fig. 4). At the same time based on the conditions that the efforts on contact pads of tongs must not exceed the yield strength of the material [$\sigma_m$], and the maximum efforts are determined by friction of contact, i.e. $R_{\max 1} = 2\mu_P P_n$, $P_n < kbl \cdot [\sigma_m]k$ – safety factor to prevent deformation of the workpiece and its damage at the site of contact.



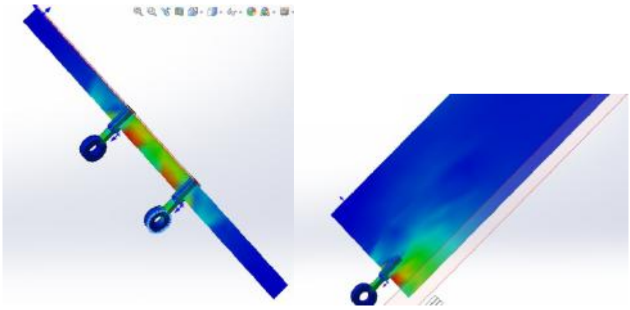


Fig. 4. Examples of the calculation of static node voltages on the model of sheet blank, the receiving loading from the mechanotronics drive of microdisplacements

Another limitation has been the amount of load $R_{\max 2} = \dfrac{\pi^2 EJ_{\min}}{4L^2}$, in which the sheet blank can loose its stability with subsequent warpage. Here $L$ – the distance between tongs; $J_{\min}$ – minimum inertia momentum, in this case $J_x$.

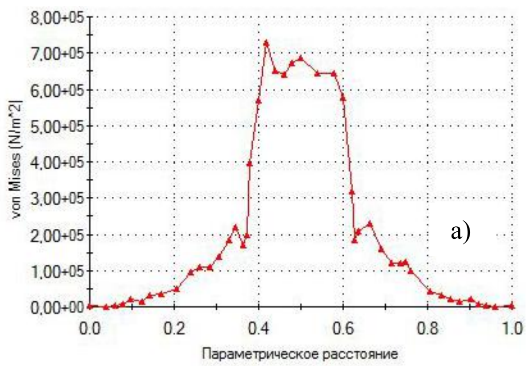
Since the workpiece is by definition a non-rigid, significant impact on improving the sustainability has its weight evenly distributed on the support surface. Thus it was obtained the stress distribution diagram for the sheet blanks from CBA and PVC-plastic of thickness 2.5 mm for certain geometric parameters of the working area.

Resulting diagrams of the stress distribution allowed to analyze the influence of the workpiece loading conditions on efficiency of waterjet cutting.

It was found that the work of drive 1 (linear loading of tongs) causes tensile stress in a layer of workpiece with rotationally symmetric decreasing diagram perpendicular to the axis of the drive (Fig. 5a), while the application of the rotation moment to tongs changes the picture and causes stress only in some distance from the axis of tongs, large in magnitude of 20-40% (Fig. 5b).

At the same time the required stress state is achieved only in immediate vicinity from the capture points (parametric distance 0.07-0.09) that for a sheet of width 500 mm is limited to 50-100 mm from the end of tongs (6). Dimensions of tongs, contact conditions and the location of tongs relative to the fend have little effect on the resulting stresses and their distribution.

It was analyzed productivity changes of cutting when moving along the axis of symmetry of drive tongs. It is easy to notice that productivity increasing is significantly in the area of occurrence of the maximum tensile stress, with increasing distance from which to the distance $L$ = 130 mm waterjet cutting process takes place as in normal conditions (Fig. 7a).



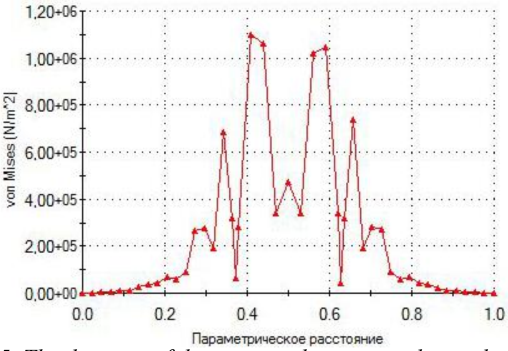



*Fig. 5. The diagram of the static node stresses obtained in the simulation loading of workpiece with line microdisplacements of tongs (a) and turning (b)*

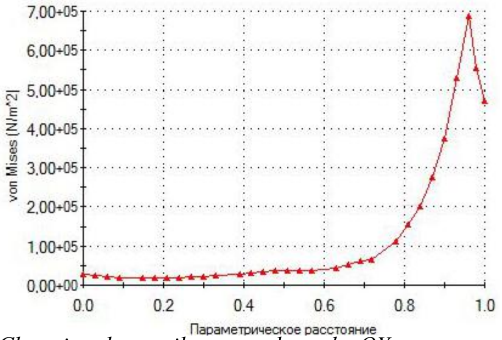



*Fig. 6. Changing the tensile stress along the OY on symmetry axis of the drive (shown relative distance in the horizontal, coordinate origin at the right edge)*

The angle of inclination of the tangent to the trajectory of movement α also has a significant impact on increasing the volume of material removal Q (see. Fig. 7b). From the calculation results it is evident that the maximum value of the angle α in the processing should not exceed the values ±π/4, that allows to build a graph of effective directions of circuit bypass (Fig. 8) for which increase of productivity takes place during cutting.

Thus, the results are the basis for the synthesis of mechatronic drive with dependent regulation in the direction of the contour. The angle between the tangent to the contour at a particular point and the symmetry axis of the working body is the input coordinates for linear movements drive (creating load R), and to the rotational movement drive (producing momentum M) .See fig. 2.3. Since the drives work requires additional energy costs, work with angles α∈[-π/8; π/8] and α∈[7/8π; -7/8π] should be carried out without pre-loading.

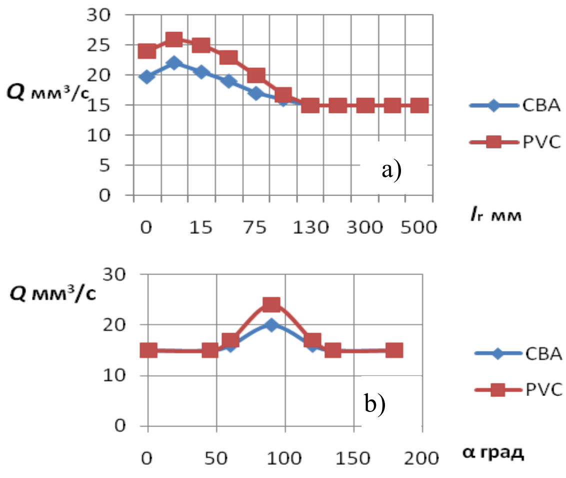



*Fig. 7. Change of productivity, expressed as the volumetric material removal at waterjet cutting depending on the distance from the edge of tongs (a) and the angle between the tangent to the contour of the cut and the axis of symmetry of the working body (b)*

Circuit of the contour in other directions should be carried out without any additional loading with lower speed of working feed *s* to ensure complete cutting, and the corresponding level of treatment quality.

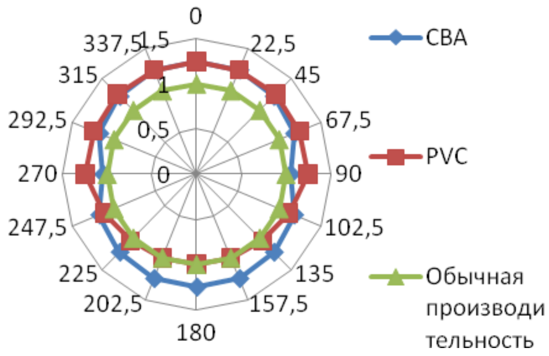



*Fig. 8. Diagram of effective directions of contour circuits*

Block diagram of waterjet cutting equipment fitted with tongs with mechatronic drives of microdisplacements is shown in Figure 9. It is based on a technical solution of waterjet cutting CNC machine presented in [6]. The introduction of two additional drives (linear loading of workpiece with effort R and with momentum M in tongs) involves facilitating feedback FB3 to determine the movement direction and introduction of an additional correction line of feedrate $K_d$, the signal from which is fed to the summation element. Moreover, the drive D1 is a leading, and the drive D2 - driven, which implies coordination of their work through the appropriate elements of the communication and adders.

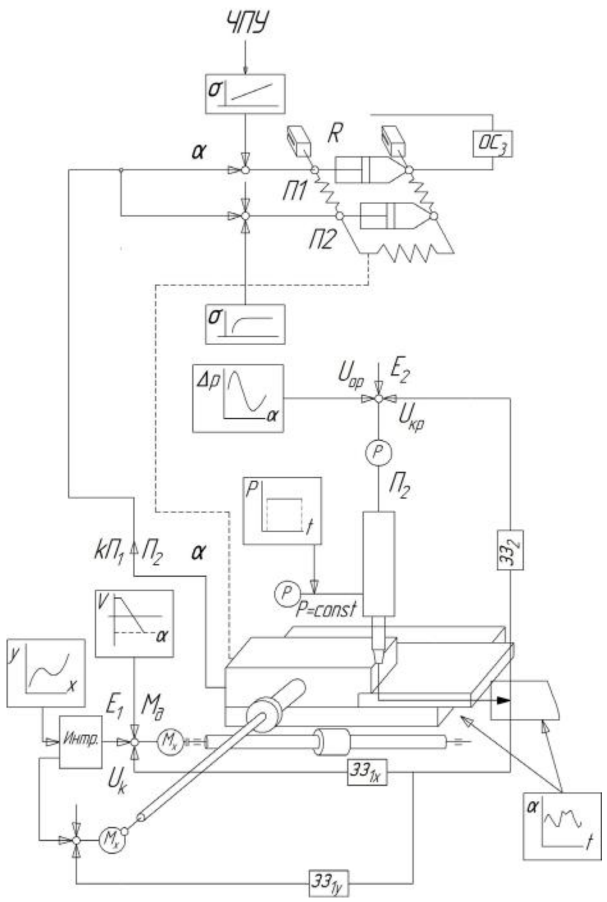



*Fig. 9. Structural diagram of the proposed technical solution*

Thus, the resulting integrated system of intensification of waterjet cutting allows to increase processing performance of viscoelastic sheet materials such as the CBA and PVC of small (up to 10 mm) thickness by 15-25% at activation of workpiece pre-loading drives by making fuller use of the main hydraulic station power of the machine.

## CONCLUSION

We have shown that the use of mechatronic drive microdisplacements in system of retention and movement of sheet blanks at a waterjet cutting process can increase productivity at a jet cutting to 25-35%, that despite increasing by 3-5% of the energy consumption is quite an effective solution.

It was found that the most effective cutting with the creation of the pre-loading of sheet blanks is with a tensile strength up to 90 MPa (PVC-plastics, PP plastic materials, certain composite materials - glass fiber laminate CBA, etc.). At the same time with an increase in the thickness more than 5-6 mm the effect is decreasing (despite the increase in pre-loading it is starting to affect the characteristics of the processes of softening and destruction on the front of destruction), and in the processing of materials with thickness over 15 mm, it is comparable to the additional energy.

The direction of generated loads must be oriented at a right angle to the tangent of movement trajectory of inkjet head, the increase in deflection angle to 20-30º leads to a small effect of reduction (not more than 10%) and a further increase in the angle leads to a growing decrease; at angles of more than 75º there is no effect.

The required loading direction for a wide range of angles of tangents to cutting contour can be achieved with joint loading of tongs with linear and rotary microdisplacements, the force is limited by the frictional force at the contact of tongs with the processed sheet blank.

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