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INCREASE OF STABILITY OF GEOMETRICAL DIMENSIONS OF HOLES ACQUAIRED BY IMPULSE HYDROABRASIVE BROACHING

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Abstract

The paper presents the results of researches of efficiency of processes hydroabrasive broaching of the holes with the means of copying method and it has been shown that the use of traditional means for this technology is extremely energy inefficient. It is noted that power losses are defined by the fact that in the hydraulic system the multiple conversions of energyoccur, in the result of which mechanical work of the actuator is converted into kinetic energy of the flow stream. However, excessive power losses are caused by cyclical execution of the holes, as the time for the positioning and deployment of the automation systems of the jet exceeds the operating time (in the case perforating of the protective screens for turbine-driven generators does not exceed 0.5 sec.). The analysis of operation of typical hydraulic unit of hydrocutting machine was being held, the results of measurements of power losses in the individual circuits are given. There were suggested to determine the energy efficiency of the process with the corresponding coefficient, taking into account not only the energy parameters but the cyclic operation of the device. There was proposed the working principle of the hydraulic system in which the energy losses will be minimized by appropriate control of the main pump.

Keywords: hydroabrasive cutting, perforating, power, energy efficiency

INTRODUCTION

In the process of exploitation of modern power equipment the gas turbine units (GTU) are the most powerful sources of continuous noise for the environment.

There are two basic directions in solving the problem of noise reduction for GTU equipment. The first is the impact on noise creating processes that minimize the generation of sound energy. The second direction is localization of the sound field in the area of generation with ensuring of energy flow of wave energy at a moderate, acceptable from the point of view of technical safety levels of the oscillations directly in a specially created noise-reducing elements of the construction.

Typically, the solution to the problem of sound absorption is most expedient at the expense of acoustically interference phenomena implemented in cell-absorbing constructions [1, 2]. They consist of a perforated sheet or layer of porous material, a proof sheet and a cellular filler situated between them. This construction is actually a set of Helmholtz resonators uniformly situated on the surface-what is quite effective in the desired frequency range [3].

However, one of the main disadvantage of given structures is the high cost of the honeycomb, due to the complicated manufacturing technology. There are also problems associated with condensate removal from the honeycomb. Therefore, such design is often performed with double-layered and a porous filling [4,5]. As the porous filler there used the tube, basalt and glass fiber, mineral woolen plates, various plastic foams, etc.

Unlike aviation, sound-absorbing constructions of gas pumping stations are made of metal sheets with a layer of asbestos cardboard and represent a complex spatial product, which task is not only reliable noise reduction during operation of the turbine, but the high effective fire protection in the emergency situation(Fig. 1).

As a rule, the perforation of such articles is a mass of holes of small diameter (about 1.2 ... 2.0 mm), performed with a step of 10 mm x 10 mm across the plane of the shell from the inside. The performance of small diameter holes is one of the most complex operations, as in this case, we obtain a contour length comparable to the thickness of the destructive layer formed on the surfaces. To improve the quality of the processed holes except the tool selection there might be used the additional technological methods, implemented the additional energy into the cutting zone, and non-traditional kinematics schemes of processing might be applied. However, such technological methods are limited by impressive size of the protective casings (more than 2-5 m) and often unsatisfactory quality of the receiving holes by themselves (Fig. 2). The drilling is done mostly manually what makes such operation extremely low-technological and low-productive due to the inconvenience and the small size of the drill.

Figure 1 – Factory covering of turbo unit GTK-10-4B

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Figure 2 – Imperfections of the received holes

In this regard, the issue of effective perforation and the search for rational ways of obtaining small diameter holes in the sound absorbing structures remain highly relevant and urgent.

STATEMENT OF MATERIAL

Currently one of the highly effective methods in given issue is the technology of hydroabrasive cutting (HAC) which has demonstrated a high competitiveness in comparison to mechanical, laser and other high-tech types of holes processing.

The most complete description of the hydroabrasive cutting process was investigated in the works of A. F. Salenko, R. A. Tikhomirov, V. Merzlyakov, Yu.S.Stepanov, V. Barsukov, V. A. Tarasov, A. A. Barzov, A. A. Shubnyakova, A. L. Kalinovskiy, A. V. Brenner, V. D. Shashurin, S. S. Savelovskiy, V. N. Poturaev, A. Momber, M. Hashish, R. Kovacevic, E. Geskin, R. Mohan, Y. Zhang, D. Aroia, M. Ramulu, J. Chao, J. Zeng and others, Daniel I., L . Tutluoglu, M. Hood, J. Bitter, V. Brenner, P. Bridgman, A. M. Yakhno, V. A. Tomowski, Duduka V. A., V. B. Strutinsky, V. P. Badah, N. V. Seminskaya [7-10], in particular in the process of broaching of the holes-in works [11-15].

Hydroabrasive stream performs cutting by using the impact of abrasive particles on the workpiece material, causing section, erosion, the effect of micromachanical processing and destructions under the influence of the rapidly changing field of local stresses [15]. The scheme, depicting the process of leakage of hydroabrasive jet on the workpiece material, shown in Fig. 3.

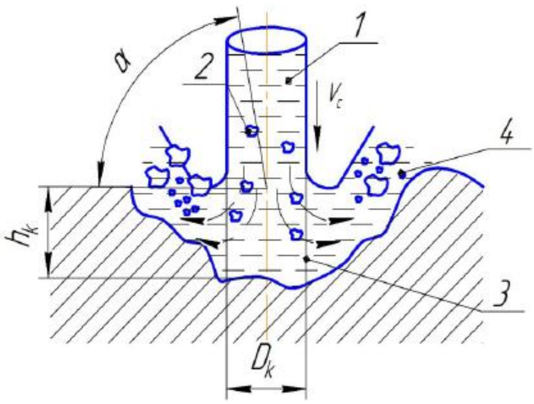


Figure 3 – Scheme of leakage hydroabrasive jet on the workpiece material:
1 – the liquid jet; 2 – abrasive particles;
3 – the cavity formed in the result of the processing; 4 – the product of erosion of the workpiece material

At the same time, despite the fact that the localization of the jet influence in small volumes allows to obtain the density of kinetic energy at 85 MW/cm^2, the ability of the jet to execute a work of destruction and to flow around obstacles selectively requires a search for new ways to improve the energy efficiency of hydrocutting. The main task arising in the implementation of jet cutting, there remains the problem of maximizing the energy of the jet [16]. As a rule, the cutting of materials by supersonic stream of pure water flowing from a nozzle under pressure up to 500 MPa takes not more than 3% of its energy to perform the useful work.

In general, the increase of efficiency of process of HAC goes by the way of increasing the pressure of the jet, which leads to a significant increase of impulse –dynamical load, required capacity and unsustainable cost increases[14].

In a number of works [17-19] there have been shown the feasibility of usage of impulse jets to enhance the cutting ability formed with a certain cycle. Pulses are generated with the direct input of energy into the water and the subsequent discharge of the water through the nozzle. In this case, the water has a speed in excess of 1500 m/s .Improving the efficiency of processing is achieved through the following:

1) The increase of the unit weight of the area of impact on the volume of water obtained from the impact stream; 2) Impact stream repeatedly provides the initial effect of hydro strikes with high lateral speed and increases the fracturing and erosion;
3) Cyclic unloading of the processed material under the impact influence cause the absolute voltage, contributing to brittle fracture;
4) Short-term impact influence of tension leads to reduction of energy losses inside the fractured material.

MATERIAL OF RESEARCH

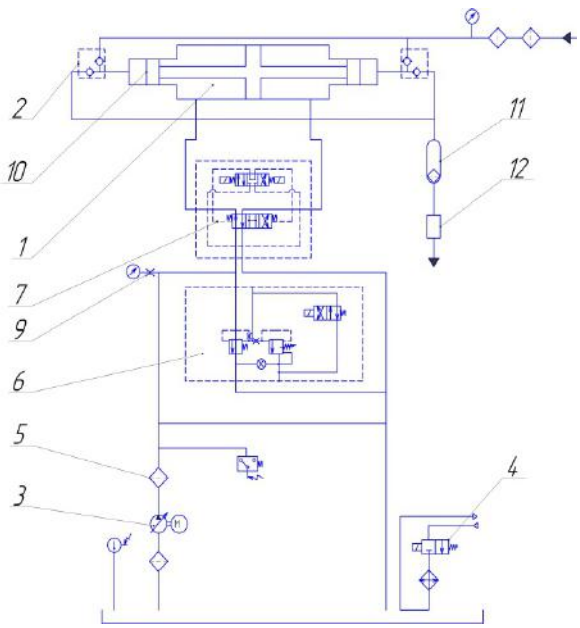
The analysis of work of the feed system with high pressure of typical hydroabrasive cutting unit is done. In the vast majority of cases, for hydroabrasive technologies of processing of high-strength materials there are used the baitcasting systems [20], which are the most simple and reliable means of creating the pressure of over 120 MPa with a flow rate of 50-150 cm3/s. Such systems consist of two circuits: a low oil circuit with low pressure (up to 12,5-15,0 MPa) and water circuit high pressure (400-600 MPa). In Fig. 4 there had been shown a schematic diagram of the structure of hydromultiplicator with double action with automatic switchover and separate circuits for low and high pressures. The drive of the multiplier is carried out by means of a power cylinder 1, the piston of which is moved periodically in one direction or another, depending on which cavity receives liquid from the auxiliary pump 3 (for example, a vane pump with a flow rate of 5 ... 120 dm3/min and pressure to 15.0 MPa). Filling with a working fluid of high pressure is provided via two inlet valves 2, performed by freely falling (without turning the springs with motion limiter). Pressure valves 4 have a different design – they are made of returning spring and a limit of pressure power. With the help of fittings and pipelines the multiplier is connected with a compensator of pressure pulsations (hydro accumulator) 11 and nozzle12 - working body.

Working fluid –the water – is being purified by slit filter 5, and the specified pressure at the lower extent of the hydraulic system is supported by the safety valve 6 of the type G52-1.

To ensure the reversal actuator there is being used a spool dispenser 7 with hydraulic control. The kinematic connection of the lever of the crane reversal 8 with a piston rod of the working cylinder is provided with adjustable stops determining the movement of the plunger. Delay time while reversal is determined by the inductors in the covers of spool dispenser 7 and the stiffness of the springs, mounted in the plate of a spool-type valve with electromagnetic control, which becomes the mean of control of the first cascade**.**

Having worked in the power cylinder, the oil flows through the throttle 9 type G55-2. Automatic control of the throttle stabilizes the number of double movements of hydromultiplier despite the degree of load. The hydraulic system works with a constant counterpressure of 0.8 ... 1.2 MPa.

The plungers 10 of the multiplier are connected with a rod with the help of self-centering devices, what allows to compensate geometrical errors and errors of mutual location of surfaces in contact. The seal of plungers in high-pressure chambers is done by a special ftorolonseals. Thus, while the work of the multiplier system, regardless to the water flow at the high pressure circuitthrough a nozzle 12, supported by the oil pressure, leads to system operation with the power consumption (1).



A

b

Figure 4 – basic scheme (a) and the photo of the hydrounit (b)

$$N_k = \frac{p_n Q_n}{60\eta}, \quad (1)$$

wherep_n –is the working pressure of the first stage formed by the pump in the low pressure circuit and is determined by the pressure gauge13, Q_n – water consumption , dm^3/min; η – total coefficient of effectivness: $\eta=\eta_{vol}\eta_m\eta_h$, η_{vol} -is volumetric efficiency coefficient, which takes into account losses in the flow of water in the pump; η_m– mechanical efficiency, which takes into account friction losses; η_h – hydraulic efficiency, taking into account the hydraulic losses in the pump. Weassume thatη=0,7...0,8.

There for, if the pressure at the output of the multiplier is determined by the ratio of the active areas of the piston of the actuator and plunger, and also determines by the overflow of liquid , by volume of plunged space, and by the volume of the accumulator, and in the first approximation it comprises $p_m = \eta_m p_n (D/d)^2$, where is η– is mechanical efficiency of the battery, η=0,9...0,95[9]; D, d- is the diameter of the piston and plunger multiplier, mm; p_n- is the pressure in the cavity of the piston, MPa, jet according to [10] of the nozzle device will flow at a speed of

$$v_{\max} = \sqrt{\frac{2n}{n-1}\frac{b}{\rho_{bo}}\left(\left[\frac{\rho_{b\max}}{b}+1\right]^{\frac{n-1}{n}}-1\right)},$$

whereρ_{bo}- is the density of the technological fluid at atmospheric pressure; ρ_{bmax} -is the density of the liquid at the pressure in the system; b – entropic function; n- is the adiabaticindex.

After the capture of abrasive particles which are entering into the mixing chamber with flow rate $M_a = f(t)$, the average speed of double phase flow will be reduced and will be:

$$v = \frac{\pi d_c^2 p_b}{2\left(\frac{\pi d_c^2}{4}\sqrt{2p_b\rho}+M_a\right)}, \quad (2)$$

where d_c – is the diameter of stream forming nozzle, and this speed is directly will be related to the massive consumption of abrasive material, which will be variable, taking to consideration the unstable nature of the broaching process, as noted by [7].

The expected power of the broached hole will be

$$N_r = \frac{ah}{4\tau}\rho_m \pi D_k^2,$$

where a - single work of destruction; h – thickness of the workpiece;ρ_m- is the density of material to be removed; τ – time of processing; D_k – diameter of the calibrate tube. The power loss in the jet-abrasive equipment is essential because it depends on multiple energy transformations in the system. Actually, the supplied energy E_e is converted into mechanical work of rotary shaft of the hydraulic pump of the first stage M_d, and then into the potential energy of the compressed fluidE_{pI}; further, there is a new conversion of E_{pI} into mechanical work of the plungers of the multiplier M_m, after which the compressed fluid has potential energy, but in the high-pressure circuit E_{pII}.

Further, following through the nozzle, there will be conversion of potential energy into kinetic energy of the K_c, with the capture of abrasive grains and a partial loss, and finally conversion into the useful work of material destruction. Each of these transformations is accompanied by various energy losses, sometimes very significant. Thus, the general scheme of energy transformations can be written in the following way:

$$E_e \to M_d \to E_{p1} \to M_m \to E_{p11} \to K_c \to R.$$

The balance of power system will be presented in the formula:

$$N_p - N_e - N_{m1} - N_{g1} - N_{m2} - N_{g2} - N_c - N_k = N_r \quad (3)$$

where N_p; N_r– is an input power and cutting power, correspondingly; N_e- is the energy loss in an electric circuit; N_{m1}; N_{m2}– mechanical power loss in the pump and multiplier, respectively; N_{g1}, N_{g2}– hydraulic power loss in circuits with low pressure and high pressure respectively; N_c – power losses in the nozzle and in the mixing abrasive system; N_r– useful cutting power. The useful cutting power can be determined by (3), or experimentally using the recommendations [4]:

$$v_a = \sqrt{\frac{1}{m}\left(2\delta_n + \frac{k_a T_p^2 \sigma_b Ra}{m z_n}\right)\frac{k_a \sigma_b Ra}{z_n}}, \quad (4)$$

where δ_n, δ_a - is the depth of the hole and its length, respectively; m- is the weight of abrasive particles; Ra, σ_b– are the parameters of roughness and the strength of the surface; z_n – grit of abrasive particles; T_p – constant which takes into account the inertia of microcutting process; k_n, k_a– constant coefficients.

In the mentioned equation all parameters except δ_n, δ_a, are known, and can be determined by the microphotos while electron-microscopic analysis of the surface after hydroabrasive cutting. Then, by setting the streak length on the surface of the cutting surface it becomes possible to set the equivalent (averaged) speed of particles’ movement, and to determine the capacity of the process. Let the sequence diagram of the operation of the multiplier system to be corresponding to the shown scheme on Fig. 5.

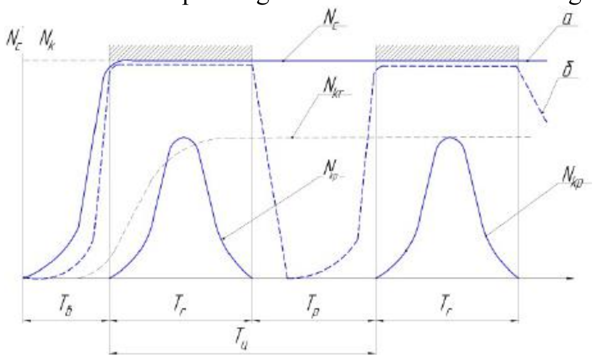


Figure 5 – sequence diagram of the operation of the power supply while the broaching of the holes:
a – constant actuation of the main drive,
b- cyclicturning off

Thus, the coefficient of efficiency of power consumption in abrasive waterjet broaching of holes will be defined by the ratio of the energy costs for doing useful work to the consumed electric energy:

$$k_e = \frac{\sum N_r \tau_r}{N_e T}, \quad (5)$$

where T –time of the equipment work. It is also believed, that the machine has a cyclical nature with timeT_u, non-stationary processes while the reverse of cylinder of the multiplier are neglected, and the establishment for a working pressure is performed by the valve in the low pressure circuit.

Receiving of the mass of holes in the procurement with a large area accompanied by a cyclical frequency of occurrence is related to the fact that along with the main time t_0 for the execution of holes with a diameter of d_0, the additional time t_d for the orientation of the working body and moving it for a certain distance is necessary, what corresponds to the step of perforation. During this time, the multiplier idles, Fig. 5, and the liquid in the circuit of low pressure begins to move through slots of safety valve for the drain in the hydro tank. Meanwhile, the power is consumed for pumping of the fluid through the low-pressure circuit in the hydraulic system, while the high pressure shutdown closes the flow of fluid of high pressure into the mixing chamber. Because of the fact, that the multiplier system, which is often used in hydrocutting systems, also works in a cyclic mode, with switching of the direction of movement of the working piston (in which the fluid discharge is performed by the right (1),or the left (2) chamber, it can be simplified to single-acting (Fig. 6).

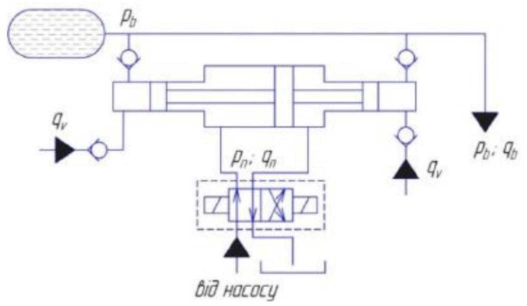


Figure 6– Hydraulic system with a reverse multiplier

Let the multiplicate system consist of a multiplier with unilateral action (Fig. 7), with spring-loaded or forced return of the piston to its original condition, have the pressure in the low pressure system and to work on the principle of creating high pressure when the multiplierpiston moves from left to right with the opening of the valve-stopping mechanism.

Then the full working stroke in the system must correspond to the time $t_0$for the broaching of the hole with the diameter d_0 at the sheet procurement with thickness h_z,with the formation of the last one by the mean of copying method.

During one working stroke (that is for the time required for forming the holes), the multiplier will deliver liquid in a volume:

$$V = \frac{\pi d_p^{\,2}}{4} l - \frac{\Delta p(q_1 + V_m)}{E} - 2.5\frac{\pi p_b (s - \Delta d)^3 td}{12\mu l_1} - \frac{p_b V_m}{E''} \quad (6)$$

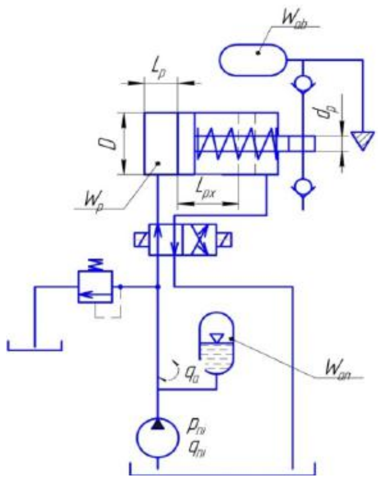


Figure 7 – Power supply system with single-sided multiplier

The time for fluid loss in one move of the multiplier will be:

$$t_x = \frac{d_p^{\,2} l - 1{,}27\left(\frac{\Delta p(q_1+V_m)}{E} + \frac{p_b V_m}{E''}\right) - 3{,}18\frac{\pi p_b (s-\Delta d)^3 td}{12\mu l_1}}{\mu_c d_c \sqrt{p_b}}\sqrt{\frac{\rho}{2}}$$

and the volume of fluid that must get into the power actuator of multiplier:

$$V_m = \frac{K_{mp}}{\eta_m}\left(\begin{array}{l}\frac{\pi d_p^{\,2}}{4} l - \frac{\Delta p(q_1+V_m)}{E} - \\ -2.5\frac{\pi p_b (s-\Delta d)^3 td}{12\mu l_1} - \frac{p_b V_m}{E''}\end{array}\right) + q' t_0 \qquad (8)$$

This volume should be ensured by the simultaneous work of the low pressure pump and the emptying of the cavity of the hydro accumulator where the compressed fluid is stored.

Because while the work of multiplier, the equilibrium of the piston is determined by the pressure p_n, generated by the pump and the back pressure in the plunger chamber, it turns out that the flow of fluid into the cavity of cylinder will be:

$$Q' = \frac{\mu_c f_c}{\eta_m}\sqrt{\frac{2}{\rho} p_b} \cdot K_{mp} + q' \qquad (9)$$

That is:

$$\mu_t f_t \sqrt{\frac{2}{\rho}\left(p_n - \frac{p_b}{K_{mp}}\right)} + Q_n = \frac{\mu_c f_c}{\eta_m}\sqrt{\frac{2}{\rho} p_b} \cdot K_{mp} + q'$$

$$p_n - \frac{p_b}{K_{mp}} = \frac{\rho}{2}\left[\frac{\mu_c f_c}{\eta_m \mu_t f_t}\sqrt{\frac{2}{\rho} p_b} \cdot K_{mp} + \frac{q' - Q_n}{\mu_t f_t}\right]^2,$$

$$p_n = \frac{\rho}{2}\left(\frac{\mu_c f_c}{\eta_m \mu_t f_t}\sqrt{\frac{2}{\rho} p_b} \cdot K_{mp} + \frac{q' - Q_n}{\mu_t f_t}\right)^2 + \frac{p_b}{K_{mp}} \qquad (10)$$

where μ_t– consumption coefficients through the edge of the valve; f_t – the area of flow section of the valve P_1. The last equation shows the relation between the pressure of liquid outflow p_b, the pressure in the line of circuit with the low pressure p_n, the flow of the liquid q, consumption of the of the pump with low pressure Q_n and the coefficient of multiplier K_{mp}. Therefore, ifp_n is a definite function $p_n = f(t)$, variable in time, and the pressure in the high pressure chamber is determined by the consumption of the liquid from the accumulator andpump and is determined by the parameters of the accumulator, we are going to get the following diagram of change of the pressure p_b(Fig. 8).

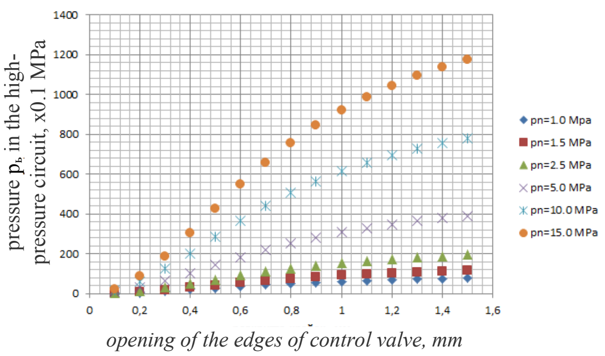


Figure 8 – Variation of pressure p_b in the high-pressure circuit while the openings of the edges of control valve, mm. Theoretical coefficient of multiplier $K_{mp}=10$

Thus, the response time of the valve must be minimal and the openings of the edges – must maximally exceed the nozzle hole d_c in a high-pressure circuit.

The formation of holes by a spurt of fluid with high pressure is defined as the geometric parameters of the holes and the thickness of the processed sheet material as well as jet flow from the nozzle.

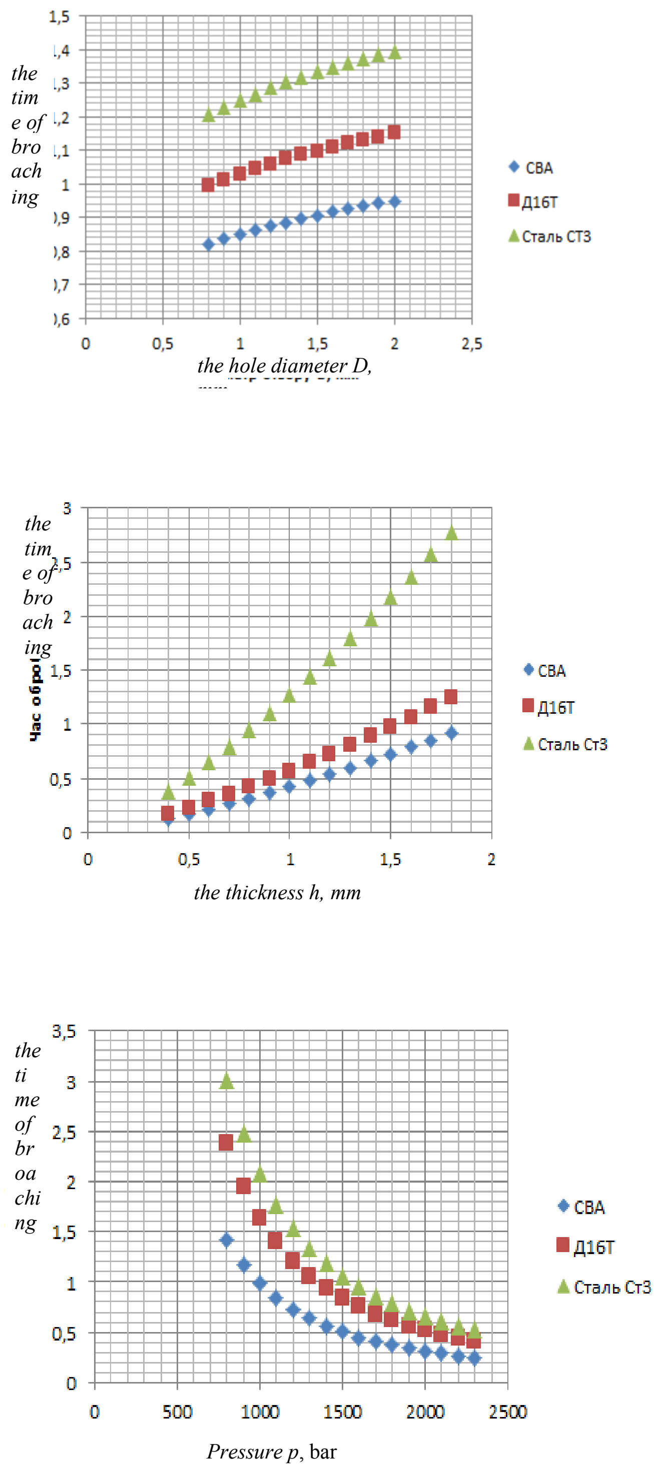


Figure 9 – Influence of the thickness h of the processed procurement, the hole diameter D and the process of fluid pressure p_b at the time of broaching of the hole t_0

The dependence for determination of the volumetric material removal rate *w*, under the condition that the supply *s* should be multiplied to the cutting depth *h* and the width of the resulting groove b, for the case when the cross section of the cut has a rectangular shape with parameters *h* and *Dk*:

$$w = 0.11\left(\frac{p_b}{100}\right)^{1.66} D_k^{1.84} h^{-0.3}\left(\frac{\sigma_p}{100}\right)^{-0.35}\sqrt{d_a}K_a^{0.73}$$

If it is taken to the account that the volume of material to be removed during the time t_0 is defined by the diameter of hydroabrasive spurt D_k as $W_0 = \frac{\pi D_k^2}{4}h$, so the time t_0 will be:

$$t_0 = \frac{\pi D_k^2 h}{4w} = 2,27\frac{\pi D_k^{0,16}h^{1,3}}{\left(\frac{p_b}{100}\right)^{1.66}\left(\frac{\sigma_p}{100}\right)^{-0.35}\sqrt{d_a}K_a^{0.73}} =$$

$$= 2,27\frac{\pi D_k^{0,16}h^{1.3}}{\sqrt{d_a}K_a^{0.73}}\left(\frac{p_b}{100}\right)^{-1.66}\left(\frac{\sigma_p}{100}\right)^{0.35}$$

The influence of the thickness h of the procurement *h*, the hole diameter D and the pressure of technological fluid p_b for time $t_0$of broaching of the hole is being shown on Fig.8The materials taken to consideration are : the glass plastic GFU, duralumin D16T, Steel St3, which are most commonly used in the protective casings of the turbines.

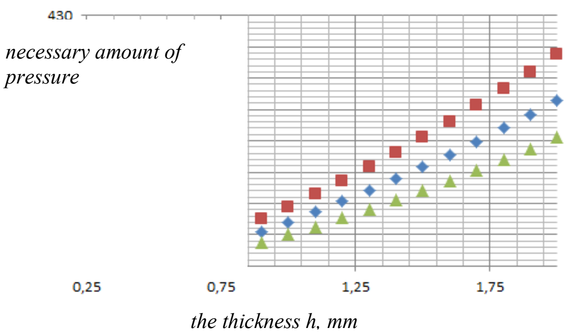
Change of the desired pressure level for performance of holes of a certain diameter for a fixed time (e.g., t_0 = 1,0 s), will depend on the thickness of the processed material h mm, it’s strength and hole diameter D_k, in mm, as shown in Fig. 9.

Thus, it becomes apparent that the minimal pressureP_{min} for broaching of the holes in the sheet materials according to the operating time should not be less than the calculated for the particular conditions of operation of the multiplier device (Fig. 10), based on the conditions of its continuous decline during discharge of the battery in accordance to Fig. 11. The cycle time is:

$$T_c = t_d + t_o = \frac{\frac{K_{mp}}{\eta_m}V + q't_0}{\mu_t f_t\sqrt{\frac{2}{\rho}\left(p_n - \frac{p_b}{K_{mp}}\right)} - Q_n} + \frac{2,27}{k_z}\frac{\pi D_k^{0,16}h^{1,3}}{\sqrt{d_a}K_a^{0.73}}\left(\frac{p_b}{100}\right)^{-1.66}\left(\frac{\sigma_p}{100}\right)^{0.35}$$

Let’s compare the durations of the working process and time of filling of the cavity of the accumulator, taking into account that: $t_o = f(p_b)$, Fig. 10.

$t_b = f(p_b)$ Thus, the cycle duration varies nonlinearly depending on the level of pressure needed for the operation of the broaching.



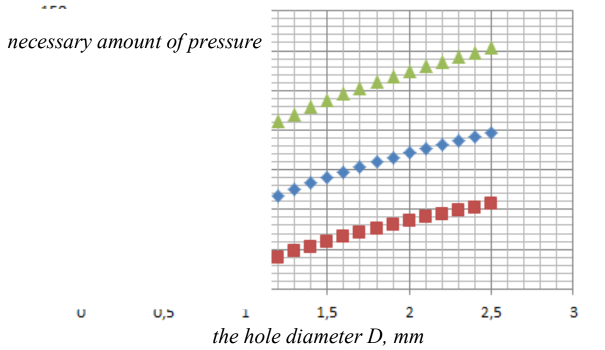


Figure 10 – Dependence of the necessary amount of pressure fluid on geometric parameters of the received hole

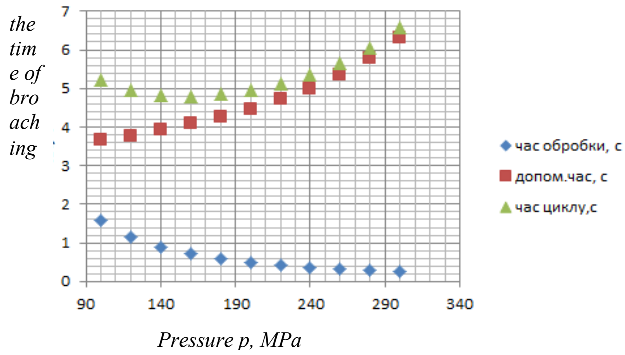


Figure 11 – Change in cycle time for different levels of fluid pressure in the high pressure circuit

So, to minimize the cycletime, the pressure of the working fluid must be installed in correspondence to constructive parameters of hydraulic system and the properties of the processed material.

To confirm the obtained dependences there were carried out experimental researches aimed at solving a number of problems: determination of power losses in the circuits of the multiplier of the hydraulic system, determination of the useful power of the hydrocutting process; the search for effective methods and tools for improving the energy efficiency of the hydrocutting while the broaching of holes.

The study was carried for sheet materials with thickness 1,5-2,0 mm with aluminum alloy AMg and steel 40X. Measuring of controlled values allowed to chart changes in load over time, to obtain data for determination of power losses in the elements of the hydraulic system (Fig. 12), and to determine the effectiveness of the perforation of the sheet blanks (Fig. 13).

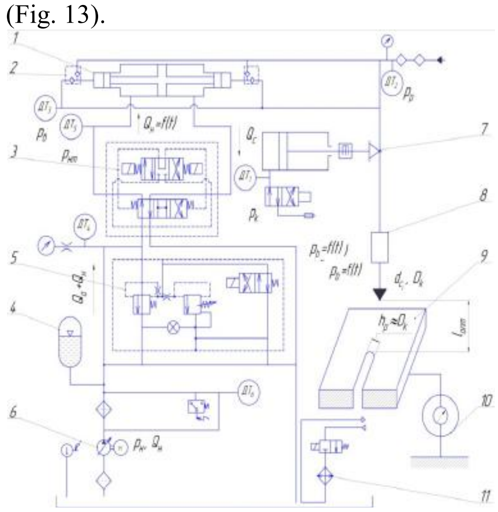


Figure 12 – Hydraulic system of the tested equipment with installed sensors

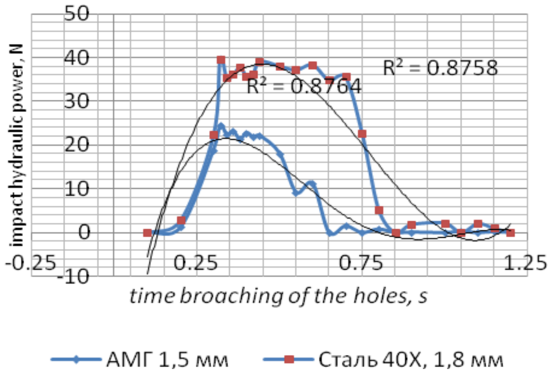


Figure 13 – Diagram of the change of efforts while broaching of the holes

Analysis of the chart of load for processed samples made of mentioned materials has showed that the time of broaching of the holes in both cases did not exceed 0.5 sec. This is explained by the fact that the thickness is negligible, and resistance to hydroabrasive destruction is quite low.

Electron microscopic study of the samples showed that the development of a funnel of destruction happens without significant bias in the shape, and the diameter of the received hole corresponds to the diameter of the slice of the gauge tube (see table. 1). However, the pressure drop below the specified level leads to increasing errors of the form, and in some cases, the process can be stopped completely (the last row of the table 1). Based on the obtained diameter from the flow pressure of the liquid at constant time and the thickness of the blank are shown in Fig. 14.

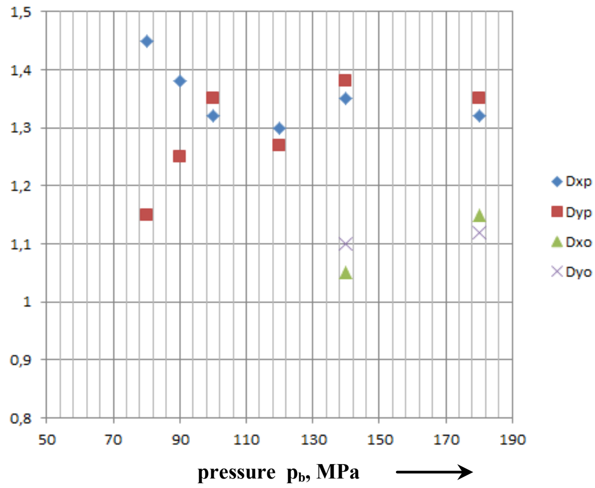
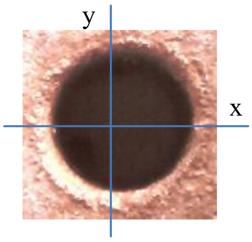
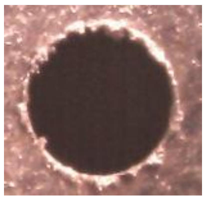
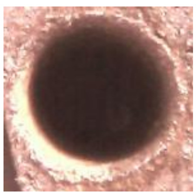
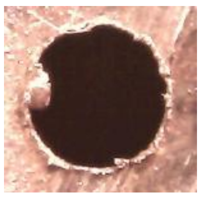
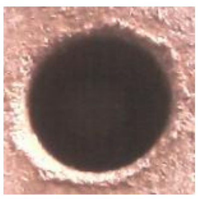
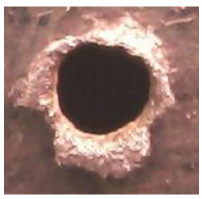


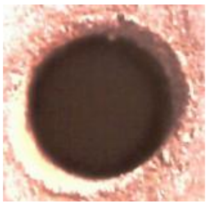
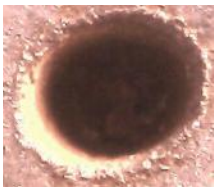
Figure 14 – Changing the shape and diameter of the hole while the pressure loss in the hydraulic system

Thus, it is clear that the formation of the holes generally must occur within the time when the pressure drop will not be significant for the case of holes in the range of 0,8-1,2 mm minimum pressure should be 120 MPa. This pressure level can be obtained after full discharge of hydro accumulatot at the end of the processing cycle.

Analysis of surface topography has proved (Fig. 15) that the surface structure is substantially different at the front of the hydrocutting process and in the periphery, which represents the surface of the hole.

Table 1 – analysis of the accuracy of the holes

№	Parameters of processing	Photos of the obtained samples, x50		Parameters of the holes	
		Straight side	Reverse side	Average values, mm	The variance of controlled values
1	p_{bmax} =180 MPa t=0,8 s h=0.75 mm d_0=1,25 mm			D_{xp}=1,32 D_{xo}=1,15 D_{yp}=1,35 D_{yo}=1,12	σ_{dxp}=0,023 σ_{dxo}=0,018 σ_{dyp}=0,015 σ_{dyo}=0,035
2	p_{bmax} =140 MPa t=0,8s h=0.75 mm d_0=1,25 mm			D_{xp}=1,35 D_{xo}=1,05 D_{yp}=1,38 D_{yo}=1,1	σ_{dxp}=0,024 σ_{dxo}=0,019 σ_{dyp}=0,018 σ_{dyo}=0,038
3	p_{bmax} =120MPa t=0,8 s h=0.75 mm d_0=1,25 mm			D_{xp}=1,30 D_{xo}=0,65 D_{yp}=1,27 D_{yo}=0,55	σ_{dxp}=0,032 σ_{dxo}=0,067 σ_{dyp}=0,027 σ_{dyo}=0,045
4	p_{bmax} =100MPa t=0,8 s h=0.75 mm		Full firmware is absent D_{xp}=1,32; D_{yp}=1,35 mm			

	d_0=1,25 mm		
5	p_{bmax} =90MPa t=0,8 s h=0.75 mm d_0=1,25mm		Full firmware is absent D_{xp}=1,38; D_{yp}=1,25 mm
6	p_{bmax} =80 MPa t=0,8 s h=0.75 mm d_0=1,25 mm		Full firmware is absent D_{xp}=1,45; D_{yp}=1,15 mm

The average length of the strokes at the bottom of the cavity is 12-18 mm, which is equivalent to the particle speed at the surface in the range of 32-36 m/s.

The computed power value are presented in table 2, which shows that losses of 1 and 11 stages of multiplier in general corresponds to the known data, and efficiency of such multiplier systems.

The data shows that the useful processing power in average is 1200 watts.

In case of analysis of the data from table. 1, 2, it becomes obvious that a significant power loss in the multiplier and the jet device are dictated by the quality of the seals, the quality of calibrating nozzle etc.

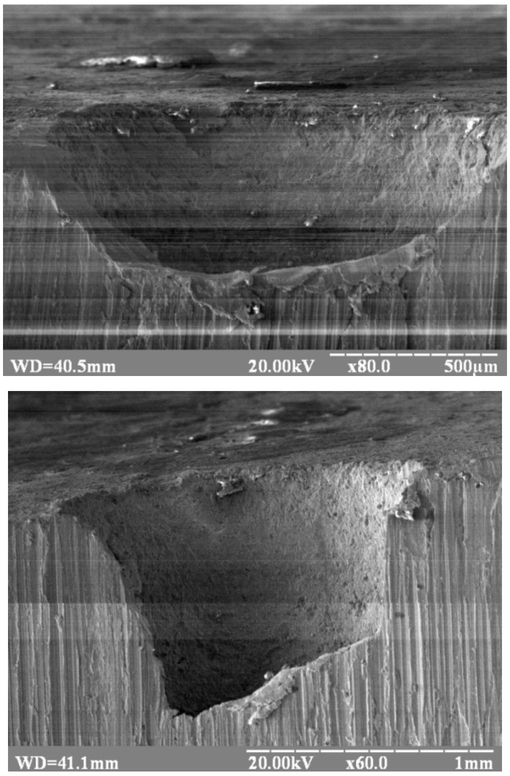


Figure 15– Microelectronic photographs of cross section of the cut while broaching the holes

Table 2 – power loss in the hydraulic circuits of the multiplier hydrosystem and useful power of hydrocutting process (pressure in the primary circuit is 12.5 MPa, and in the second- 260 MPa)

Elements	The estimated capacity of the elements, kW	The measured power, kW	Power loss, kW
1	Drive motor, Np=40,0 Cutting power Nr=1,18	N_p=36,9	
2	The hydraulic system of the first circuit N1=32,18	N_1=30,23	6,67 – heating of the actuator and the hydraulic reservoir
3	The multiplier	29,2	1,03
4	Hydraulic system of high pressure N11=24,8	N_{11}= 23.54	5,66 heating of the hydro pipe of the high pressure fluid to flow
5	The jet power N_c =15,7	N_c=13,27	10,27 – loss on heating The 12.9 – loss at the end of the jet and heating
6	Cutting power N_r=1,18	N_r=1,18 kW	12,9 – loss for floating out the spurt and heating
General power losses, kW			35,72

However, the comparison of the coefficients of the consumed power shows that significant energy efficiency improvements depend on the proper adjustment of conditions of operation of the main drive unit of a high pressure.

Comparing the time needed to obtain stable sizes of holes of a certain diameter requires the increase of amount of liquid in the accumulator up to the level when the pressure drop in the pipe will not result in significant deviations of the shape or incomplete cutting of the procurement (table.1, the last line).

Thus, the actuator control in circuit with low pressure can significantly affect the energy efficiency of the overall system functioning. Therefore, the reduction of energy consumption while hydroabrasive perforation of the soundproof panels of turbine units should be provided by new technical solutions in the power circuit with low pressure

CONCLUSIONS

As a result of researches there has been established the losses of working capacity in the main drive of hydroabrasive machine and it has been shown that such losses can be significant and could reach 80-90%. It has been shown that while the broaching of the mass of holes by the hydroabrasive spurt by the method of copying the used capacity loss are increasing because the time of the operation is much less from the time for the orientation of the jet head and the operation of systems of the jet interruption.

To evaluate the effectiveness of technical solutions towards the improvement of the hydrocutting system it has been proposed to use the coefficient of efficiency of power consumption which is determined by the conditions of perforation.

Also, there had been composed the balance of power and analyzed in details the causes and locations of energy losses of hydrocutting equipment. The tests of serial hydrocutting machine were held and it has been shown that the existing technical solutions cannot be used for perforating of sheet procurements. So, investigating of the main drive of the existing equipment, it is concluded that a substantial increase in the energy efficiency of processing can be achieved using a pump with the dependent variable flow, connected to the accumulator in the low pressure circuit, the cyclic operation of which is coordinated with the additional time of technological process.

It has been shown that it is possible to acquire the holes of a given geometric shape with sizes up to 1, 2 mm in the protective casings of the hydraulic units in the case when in the proposed hydraulic system the pressure drop of fluid per cycle of procuring would occur to a level of 120 MPa, while the accumulator by itself should be designed so that its emptying time would be larger for 20-25% comparing to the cycle of receiving of the hole.

REFERENCES

[1] Shmanev, V. A. Struynaya gidroabraztivnaya obrabotka detaley GTD / V. A. Shmanev. – Moscow: Mashinostroenie, 1995. – s. 144.

[2] Besedin, S. N. Razrabotka I sozdanie novogo klassa avtonomnyih energeticheskih ustanovok maloy moschnosti dlya ob'ektov magistralnyih gazoprovodov // S. N. Besedin, V. A. Rassokhin, L. L. Plaksin, N. A. Zabelin, I. S. Kharisov // Naukaitehnika v gazovoypromyishlennosti. No. 4. – 2010. – s. 99.

[3] Piffer, A., Mayer, R. Patent. Russia, MPK F02 C7/045. Shumoglushitelpreimuschestvennodlyaaviatsionnyihdvigateleyiskladchatyieyacheykikakzvukopogloschayuschiy element (Russia); DerzhNDIHP, no. 2392462; Declared 28.10.05; Published 10.12.08, Bull. no. 17

[4] Salenko, A. and Fomovskaya, A. (2008), “Some aspects of composite materials hydro jetting from the point of the Linear Mechanic Destruction”, Journal of the Technical University of Gabrovo, vol. 6, pp. 23-33.

[5] Salenko, O., Strutinskiy, V. and Zagirnyak, M. (2005), Efectivnegidrorizannya: monographiya [Effective waterjet cutting: monograph], Vipol, Kiev, Ukraine.

[6] Wang, J. Abrasive Water Jet machining of engi-neering materials. Trans Tech Publications, 2003, Uetikon, Zuerich.

[7] Provolotskiy, A.E. (1989), Struyno-abrazivnayaobrabotkadetaleymashin [Jet-abrasive processing of machine parts], Technologiya, Kiev.

[8] Voynehovskiy, B.V.(1971), “Investigation of jet discharge under pressure of 200 MPa”, Dynamics of continuous medium, Issue. 9, pp. 42-49.

[9] Bridgman, P. The Physics of High Pressure, First edition, Dover Publications, Inc., New York, 1970.

[10] Hashish M., “Cutting with Abrasive–Water jets”. – Mechanical Engineering, Mar. 1984. – pp.60–66.

[11] Mana, O. M. Preventing the degradation of composite materials during the performing jet-abrasive drilling small holes / O.M. Mana // Promislovagidravlikaipnevmatika. № 3(37). – Vinnitsya, 2012. – S. 107–118.

[12] Mendi, Z. Modelling of Abrasive Water Jet turning / Z. Mendi, Z. Imam //Australian Journal of Basic and Applied Sciences. №5(8). – 2011. – S. 70-79.