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STUDY OF THE MOTION DYNAMICS OF THE CUTTING TOOL OF THE AUTOMATED DEVICE FOR BRICK BLANKS FORMATION

The given research considers the main problems of brick production development, identified the most cost-effective method of brick production, provided a scheme of step-by-step formation of bricks by plastic method and determined the stage at which the modernization of the equipment for brick production should be made. Main operational and quality characteristics of building bricks are clarified. The urgency of improving the technological equipment for the formation of brick blanks is substantiated. The construction and principle of operation of some domestic automatic devices for cutting clay bar into brick blanks are analyzed, their main advantages and disadvantages are determined. The variant of improving the element of the production line of brick formation by replacing the mechanical structure by the automated device, built on the principle of mechatronic system is proposed. The hydraulic circuit of the automated device for the formation of brick blanks is composed. Mathematical model of the motion dynamics of the cutting tool of this device is developed, the model is represented by a system of differential equation, containing the equation of balance of forces and flows. Simulation study of the motion dynamics of the main actuator of the automated device for bricks formation in the environment MATLAB Simulink is carried out, as a result, the dependences of acceleration, speed and coordinate of the cutting tool motion, as well as the pressure in the pumping station on time were obtained. In addition, the dependence of the movement of the cutting tool on the time during the change of the cutting tool mass and change of the technological load force was determined. In the course of the research, the time of reaching the clay bar by the cutting tool and the time of its complete displacement were determined, and the value of the pressure in the pumping station was recorded. The dependences of the influence of the most important factors on the motion dynamics of the cutting tool of the device for raw brick blanks formation were also determined. Such factors were: reduced mass (in general inertia) of the moving parts of the cutting tool; technological load; the friction force that occurs during the movement of the cutting tools of the device.

Key words: *device for brick formation, drive speed, mathematical model, working fluid consumption, pressure, power, friction force, loading at cutting bricks.*

Introduction and relevance of the subject of the research

Recently the volume of the construction has been constantly growing in Ukraine, this growth stabilized the production of the construction materials, in particular, the ceramic construction bricks. On the territory of our country more than 200 brick production enterprises are located. Greater part of these enterprises are located in Kyiv, Sumy, Lviv, Donetsk, Zhytomyr, Ivano-Frankivsk regions. But important share of the market is occupied by small manufactures, their enterprises are often equipped with the outdated equipment, this does not allow to obtain the high quality production, which would be able to compete with foreign products. It should be noted, that the production of the brick is energy-consumption process and in combination with the usage of the outdated equipment end cost grows and competitiveness decreases.

Main problems of brick production development are:

1. Incomplete loading of the production facilities.
2. Outmoded production technology.

The most widely spread and most cost efficient method of bricks manufacture is the method of the soft clay plastic formation, the process is performed in several stages (Fig. 1).

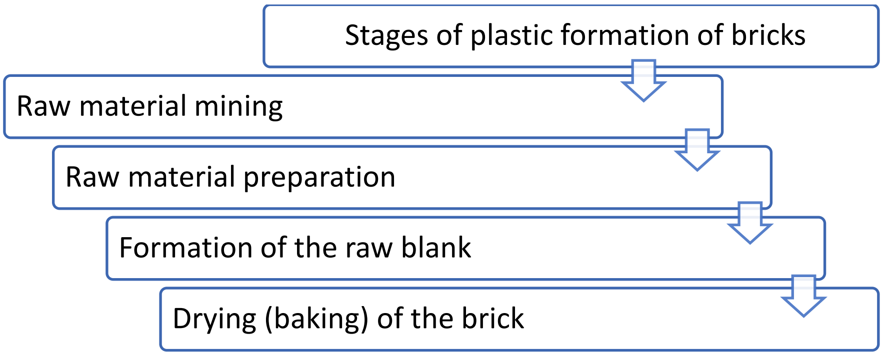

Fig. 1. Stages of plastic formation of the bricks

In our opinion, the modernization of the bricks production first of all should be performed at the stage of the raw blank formation. At this stage the most important characteristic is the correctness of the blanks dimensions and rate of their manufacture. Formation is performed in the following way: raw clay bar, located on the conveyor, is automatically cut into blanks of a certain size. At the majority of the brick manufacturing enterprises, the raw material base is located near the enterprise, this fact minimizes the expenses for the delivery. Along with cheap labor resources which do not require high professional skills, such enterprises may be cost efficient, providing the quality of production which is competitive on the market of Ukraine.

Formation of a single brick blank from the continuous clay bar, performed by means of the construction of the mechanical device, negatively influences its geometrical dimensions. It is generally believed that the strength and correct geometrical form are basic operational and quality characteristics of the construction bricks. The task of improvement of the technological equipment for the formation of the bricks blanks nowadays is extremely urgent for the enterprises of Ukraine.

Analogs of the technological equipment, used for bricks formation

At the internal market such devices are the analogs of the investigated equipment: multiwire cutting automate MPA-14/3 manufactured by the company «Techno-Bio-Energo-Service», Sumy and universal cutting automate PL 505, manufactured at Private-Joint-Stock Company «Kharkiv Machine-Building Plant «Plinfa».

Multiwire cutting automate MPA-14/3 is designed for cutting measuring bar for brick production. It consists of the frame, drives, input band table, low pushing device, rolling shafts, elevating table, string holders with the stretched strings, upper pushing device, string cleaning mechanism and discharge table, audit conveyor. The advantage of MPA-14/3 automate is high performance, formation of fourteen brick blanks per cut, small cycle of one bar cutting 8 – 12 sec. The drawbacks of this device include large dimensions, mass, fixed quantity of the formed pieces per cut, additional (elevating) table in the construction of the cutting automate and the necessity to cut the clay bar of the needed size during the previous operation.

Cutting automate PL505 is designed for continuous cutting of the bar into pieces of the preset length and their transfer to further equipment. Cut is performed only from the top downward. After each cut the strings cleaning is done. Due to the original and well considered construction automate PL505 has the following features: cutting carriage with the reliable system of roller slides; holders of the cutting strings with the system of roller slides and cutting slides, located diagonally; strings break sensors; cutting is performed by means at the cranks mechanism and servo-drive, located in the upper part of the cutting automate. The advantages of the PL505 automate are its versatility, that enables to form for 1 to 6 pieces during one cut, as well the possibility to manufacture not only bricks of the standard dimensions but also narrow- format bricks. Automate has small cycle time of the cut – 4 sec. The drawbacks of this equipment are very large dimensions and high installed power 7.8 kW.

Basic preconditions

The variant of improvement the multiwire cutting unit designed for bricks formation of the production line by means of replacement the mechanical construction by the automated device, constructed on the principle of the mechatronic system is suggested below, functional diagram of the device is presented in Fig. 2.

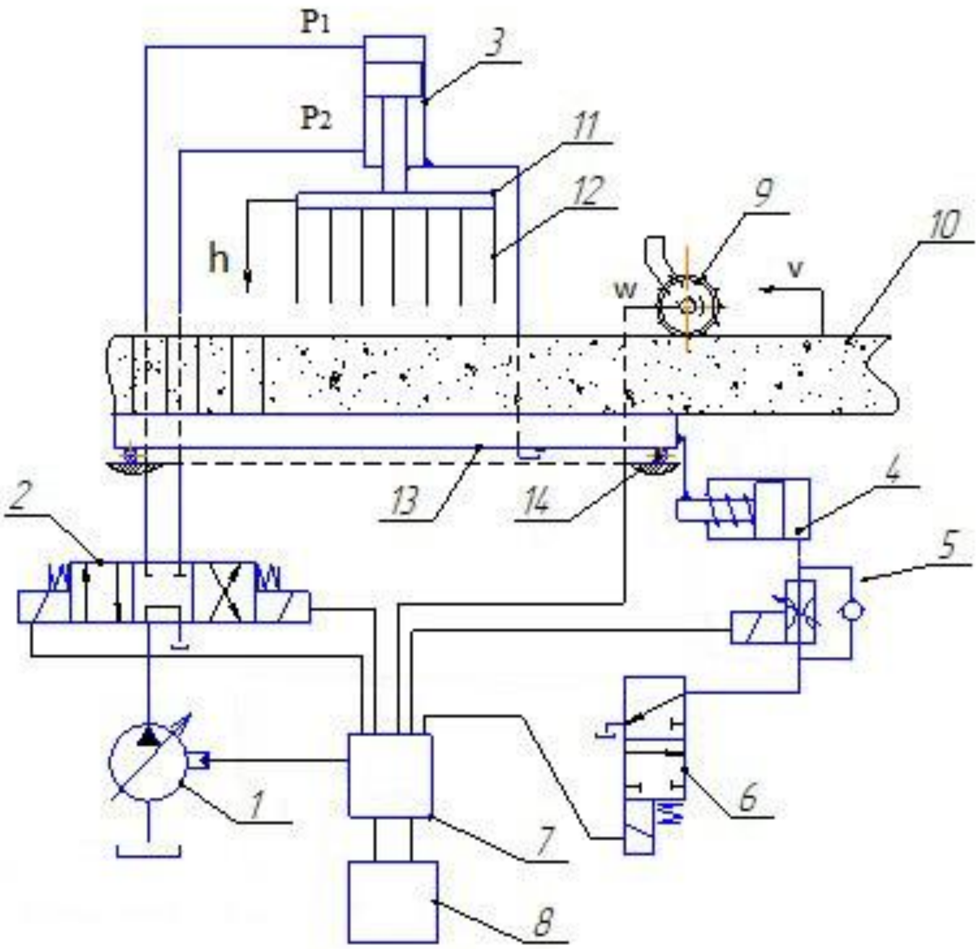

Fig. 2. Hydraulic circuit of the automated device, designed for brick blanks formation

The device consists of the following elements: 1 – pump of variable capacity with the remote control; 2 – primary three-position four-line distribution valve with electromagnetic control; 3 – hydrocylinder of the primary operation motion; 4 – auxiliary hydrocylinder; 5 – flow regulater with proportional control and reverse valve; 6 – two position three line distribution valve with electromagnetic control; 7 – controller; 8 – self-contained supply unit; 9 – motion sensor; 10 – clay bar; 11 – cross-bar; 12 – cutting elements; 13 – moving base; 14 – roller bearing units.

Automated unit for the briks blanks formation operates in the following way. As the clay bar 10 moves, sensor 9 calculates the size of the n^{th} quantity of the brick blanks (depending on the number of the cutting elements 12) and sends electric signal on the control unit 7. The latter forms signals for the distributing devices 2 and 6. Working fluid consumption from the pump 1 is directed via distribution devices 2 and 6 on operating hydrocylinders 3 and 4. Hydrocylinder 3 sets in motion the cross bar 11 with cutting tools 12 for the formation of brick blanks. Hydrocylinder 4 simultaneneosly provides synchronization of the base 13 motion, which is located on the roller bearing supports 14, with the motion of the clay bar 10. Such scheme of motion provides the lack of the relative motion between the cutting tools and clay bar, that provides the correct geometry of the brick samples during the bar cutting [1].

Main part of the research

As it was mentioned above, at the stage of raw brick blank formation, the most important characteristuics are the correcctness of the geometrical dimensions of the blanks and production speed. That is why, main tasks of the research are to determine the duration of the transient and the working motion of the automated device for brick blanks formation.

Dynamics of the cutting tool motion is considered at a steady-state operation mode of the variable capacity pump and is reprecented by the system of the differential equations (1), which contains the balance equation of the forces and flows [2, 3, 4].

$$m_{rd}\,\frac{d^2h}{dt^2} + b\,\frac{dh}{dt} + F_f(v,p,p1,\tau) + F_{tech} = p1\cdot S1 - p2\cdot S2\,;$$

$$Qp = S1\cdot\frac{dh}{dt} + \mu\cdot f_v\sqrt{\frac{2(p_1-p_2)}{\rho}} + k\cdot W_s\,\frac{dp1}{dt} + k_{r.mp}\cdot W_{r.mp}\,\frac{dp1}{dt}; \qquad (1)$$

where m_{rd}, h – is the reduced mass and the coordinate of the cutting tool motion correspondingly; b – is the viscous friction coefficient; $F_f(v,p,p1,\tau)$ – is the friction force; F_{tech} – is technological load; p_1 – is the pressure of the pumping station; p_2 – is drain pressure; S_1 , S_2 – is the surface of piston and rod cavities of hydraulic cylinder, correspondingly; Q_p – is pump station output; Q_v – is the consumption across overflow valve; k – is the compliance factor of the working fluid; W_s – is the volume of the supply line; $k_{r.mp}$, $W_{r.mp}$ – is the compliance factor and volume of the flexible pipe correspondingly; μ-is flow coefficient; f_v – is the surface of the valve working window; ρ – is the density of the working fluid.

Study of the given model was carried out in MATLAB Simulink environment. Simulation modeling is performed for the drive of the cutting tool. Simulation modeling of the system of differential equations (1) is shown in Fig. 3.

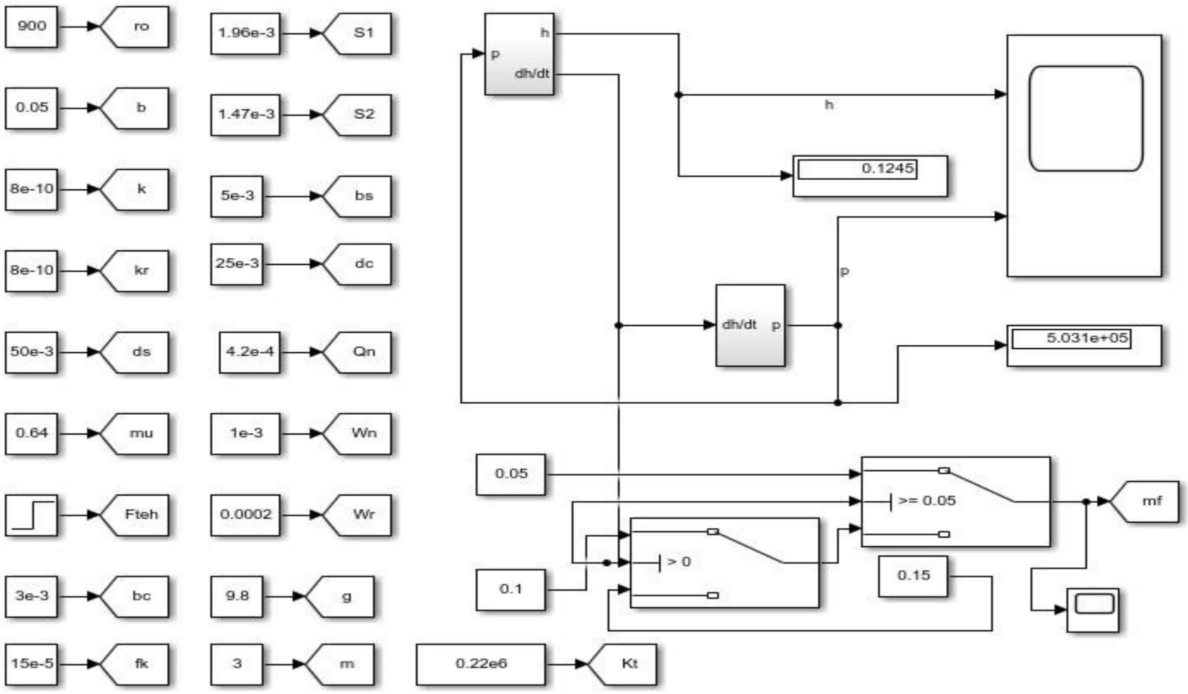

Fig. 3. General view of the system in MATLAB Simulink environment

Frictional force F_f, which is the part of the forces balance equation is one of the most important negative factors, directly influencing the speed of the cutting tool motion of the technological equipment. Mathematical interpretation of this value was presented by the «falling» characteristic [5, 6], depending on the immobility time of the function element. For the given model frictional force is taken as a constant value.

Force of the technological load F_{tech}, occurring in the process of the raw clay bar cutting was determined by means of the Newton formula, as the resistance to the motion of the cutting strings in the raw clay environment, of the ρ_{cl} density at a rate of υ.

$$F_{tech} = C_x \cdot \rho_{cl} \cdot S_x \cdot v^2,$$

where S_x – is the area of the cutting tools body projection, perpendicular to the direction of the motion; ρ_{cl} – is the density of the raw clay; v – is the rate of the cutting tools motion; C_x – is the coefficient of the body resistance in the environment, which is the function of the Reynolds number and depends on the form of the body.

In the equation of the flows balance the component $k_{cl.fr} \cdot W_{cl.fr} \frac{dp1}{dt}$ represents the volume of the working fluid, spent for filling the volume in case of the flexible hose deformation. Elastic properties of the flexible hose were presented by the rheological model with the account of static $E_{st.cl.fr}$ and dynamic $E_{d.cl.fr}$ elastic moduli [7, 8, 9].

Proceeding from the assumption that maximum admissible time for the working motion of the cutting tool under a known length of the rod motion of the hydrocylinder must not exceed one sec. and the cutting speed, accordingly, must exceed 0.25 m/sec and having solved the system of the differential equations relatively the speed of the cutting tool, the dependences of the values, describing the motion of the executive device for raw brick blanks formation were obtained, these values include: acceleration – a (Fig. 4), speed – v (Fig. 5) and cutting element motion coordinate – h (Fig. 6), as well as pressure at the output of the pump – p (Fig. 7).

Initial values of the variables: a_0=0 m/sec^2, v_0=0 m/sec, h_0=0 m, $p_1(0)$=0 Pa.

Dependences obtained at the following values are shown: m_{rd}= 3 kg, b=0.05 N·sec/m; F_f=50 N; p_1=20 MPa; $p_2=0.5$ MPa; S_1=0.00196 m^2; S_2=0.00147 m^2; $Q_н$=0.00042 m^3/sec; $k=6\cdot10^{-10}$ m^2/N; Wp=0.001 m^3; μ=0.64 m/sec; f_v=15·10^{-5} m^2; ρ=900 kg/m^3; $k_{r.mp}$=8·10^{-10} m^2/N; $W_{r.mp}$=2·10^{-4} m^3; v=0.3 m/sec; C_x=9 m/sec; ρ_{cl}=1750 kg/m^3; S_x=10.5*10^{-3} m^2.

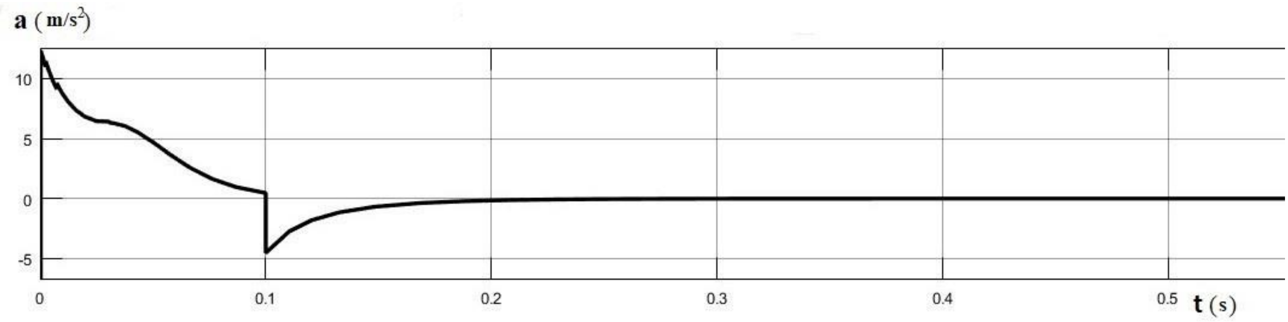

Fig. 4. Dependence of the cutting tool acceleration on time

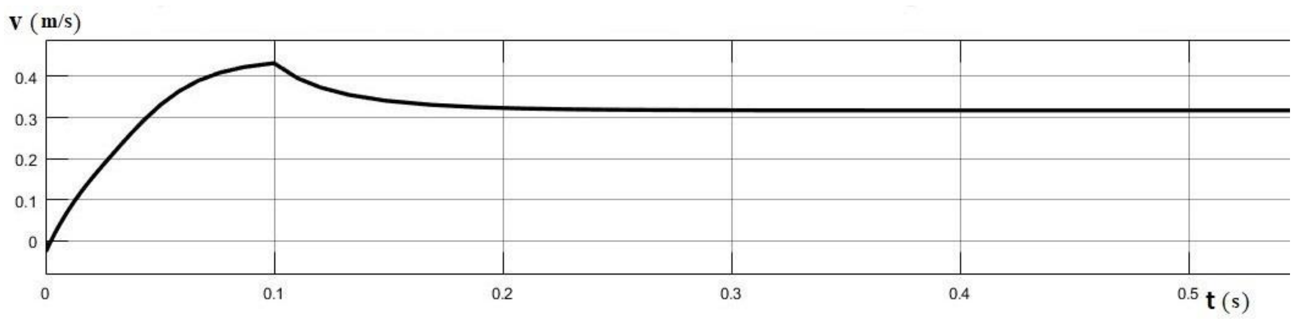

Fig. 5. Dependence of the cutting tool speed on time

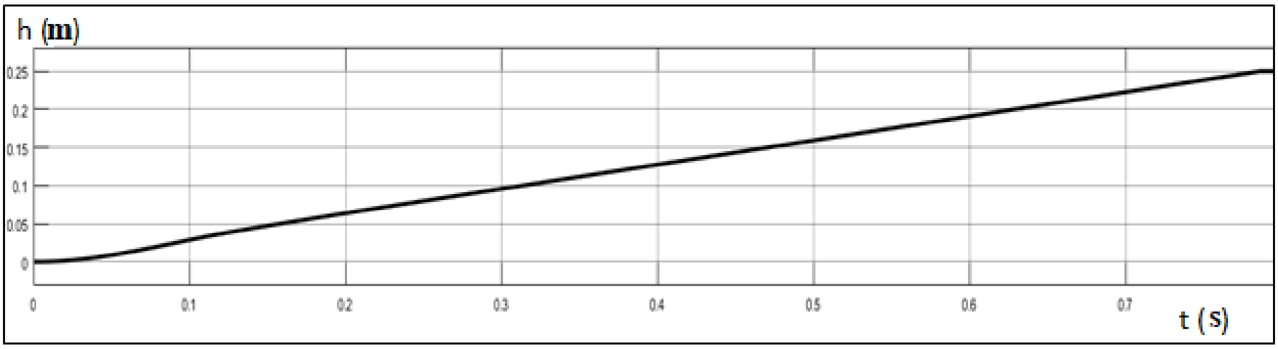

Fig. 6. Dependence of the cutting element motion coordinate on time

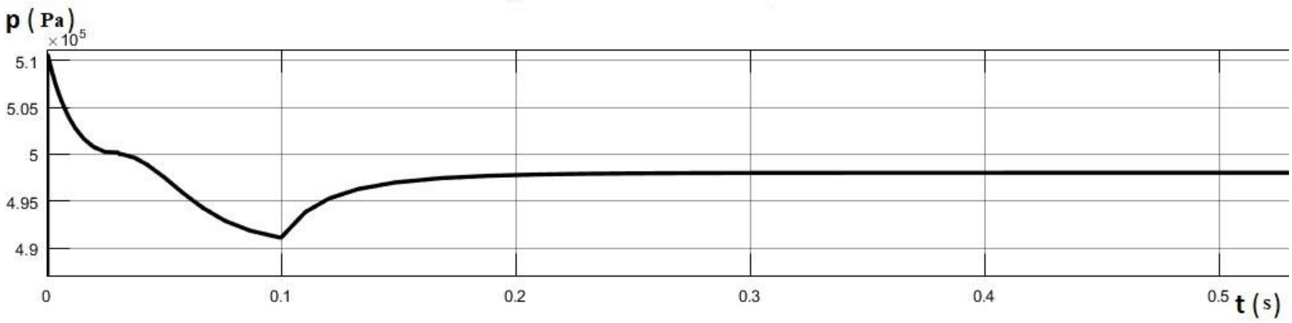

Fig. 7. Dependence of the pressure in the pumping station

Dependence of the cutting tool displacement on the time in the process of the cutting tool mass and force of the technological load change is shown in Fig 8.

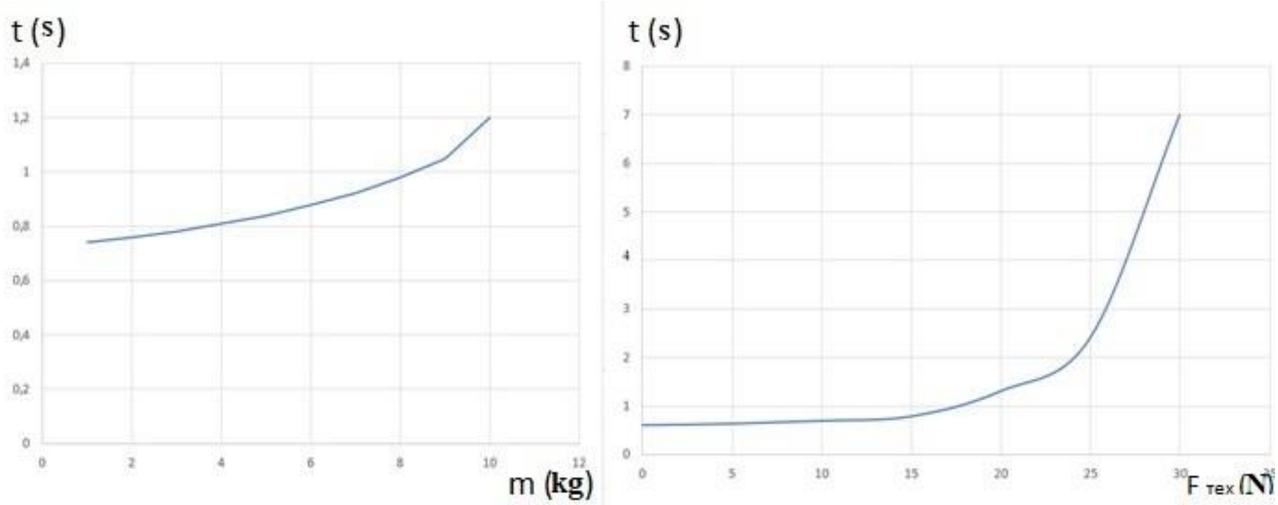

Fig. 8. Dependence of the time of the cutting tool displacement in the process of the cutting tool mass and force of the technological load change

Conclusions

In the process of the study it was revealed that the transient processes in the system occur during the time of 0.1 sec. before the start of the cutting. The complete displacement of the cutting tool is performed during 0.78 sec., that is within the limits of the preset time. The pressure value in the pumping station is $5 \cdot 10^5$ H/m^2. The dependences of the most important factors impact on the motion dynamics of the cutting tool of the device for the raw brick blanks formation are determined. These factors are the reduced mass m_{rd} (drift on the whole) of the moving parts of the cutting tool; technological load F_{tech}; frictional force F_{fr}, occurring in the process of the cutting tool motion.

REFERENCES

1. Purdyk V. P. Adaptive hydraulic drive of the equipment for the formation of brick blanks / V. P. Purdyk, V. G. Sapozhnik // Materials of the XXII International scientific engineering conference «Hydroaeromechanics in engineering practice», Cherkasy-Kyiv, May 23 – 26 2017. – P. 123 – 124. (Ukr).

2. Kozlov L. Digital PD controller for dynamic correction of the differential component coefficient for mechatronic hydraulic system / L. Kozlov // Tehnomus journal: Proceedings of the XVIIth International Conference «New Technologies and Products in Machine Manufacturing Technologies». – Suceava, Romania. – 2013. – C. 120 – 125.

3. Kozlov L. G. On the possibility of the improvement of the dynamic characteristics of the mechatronic drive of the mobile machine / L. G. Kozlov // «Hydraulic and pneumatic drives of the machines – modern achievements and applications». IIth International scientific engineering conference 15 – 16 November 2016 : Collection of abstracts. – Vinnytsia : T. P. Baranovska, 2016. – P. 122 – 116. (Ukr).

4. Popov D. N. Dynamics and regulation of the hydraulic and pneumatic systems / D. N. Popov. – M. : Machinebuilding, 1976. – 424 p. (Rus).

5. Badenkov P.F. Rubber---the constructive material of machine -building / P. F. Badenkov, V. F. Evstratov, M. M. Reznikovskyi. – M. : Chemistry, 1967. – 326 c. (Rus).

6. Busarov Ya. P. Mathematical model of the hysteresis of the external friction / Ya. P. Busarov, M. S. Ostrovskyi // Machinebuilding. – 1976.– № 5. – P. 51 – 82. (Rus).

7. Experimental study on dynamic pipe fracture in consideration of hydropower plant model / K. Ishikawa, Y. Kono, A. Haga [et al.] // Annual Journal Water Science and Engineering. – 2009. – № 2 (4). – P. 60 – 68.

8. Compression modulus of the rubber sleeves with metal braids / V. N. Prokofiev, I. A. Luzanova, V. G. Vybornov [et al.] // Mechanics of machines. – 1975. – № 49. – P. 47 – 55. (Ukr).

9. Purdyk V. P. Experimental study of the dynamic characteristics of the flexible sleeves of high pressure / V. P. Purdyk, M. Ya. Pozdniakov // XIV International scientific-engineering conference АС ПГП. Industrial hydraulics and pneumatics, Odesa 18 – 19 september, – 2013. – P. 130. (Ukr).

10. Bashta T. M. Hydropheumatic drive and hydropneumatic automation / T. M. Bashta. – К. : Machinebuilding, 1972. – 320 p. (Rus).

11. Chernykh I. V. Simulink: environment for the creation of the engineering applications / I. V. Chernykh. – M. : Dialog, 2003. – 236 p. (Rus).

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