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Research paper

Dynamics of Adaptive Drive Equipment for Forming Billets Bricks

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Abstract

Abstract. In this paper, an option is provided for upgrading equipment for the formation of raw bricks by creating a compact design with an adaptive drive based on hydroautomatics. The basis of modernized construction is the further scheme of formation of executive bodies on the movement of workpieces. A mathematical model of equipment was developed that takes into account the peculiarities of the formation of forces of friction that arise during the movement in the executive power bodies and their inertia. As a result of the study of a mathematical model in the Matlab Simulink environment, the influence on the dynamics of motion of the main executive bodies of some parameters of the drive system is determined. It is noted that the dynamics of the drive is most affected by such parameters as the weight of moving executive bodies, the friction force is given, the hydraulic stiffness of the pressure line of the pumping station is given. The method of calculating the power of the pumping station of the adaptive drive was proposed, on the basis of which the design documentation was developed and the prototype of the equipment was manufactured.

***Keywords**: billets bricks; dynamics of adaptive drive.*

1. Introduction

In the domestic industry of building materials, such as bricks, there are still many enterprises with outdated equipment, which does not allow to produce quality products. Despite these circumstances, these enterprises can be cost-effective due to the fact that for many of them the raw material base is located directly on their territory, which determines the minimum logistics costs for the delivery of the main raw material, the presence of local, relatively inexpensive, labor resources, which are not subject to high qualification requirements and other factors. In case of even partial modernization of technological equipment of such enterprises their effectiveness may increase and strengthen the status in the market of construction materials.

One of the most problematic places for the technological equipment of the aforementioned enterprises is the stage of formation of solid bricks from solid wet clay, which is realized by a mechanical device of double oscillatory motion and does not allow to obtain the necessary geometry. And considering that strength and geometric sizes are the main operating and qualitative characteristics of the brick in accordance with the standard, the solution to this problem is relevant.

Machine-building plants produce a significant nomenclature of equipment for brick factories of varying complexity and, accordingly, different productivity and different levels of automation of the technological process of brick production.

Productive cutting machines are constructions, which use a lot of cutting elements, usually strings, and which, in addition to increased productivity, can provide the correct geometry of bricks. The main drawback of such machines is the relatively high cost and large dimensions, which require significant production space. The latter factor, as a rule, becomes the biggest problem in the case of the introduction of such machines in existing production lines at small enterprises.

Fig. 1: PL500 multi-stage cutting machine

There are still a number of designs of cutting machines, in which the cutting process is continuous, in contrast to the constructions discussed above, where the cutting process is cyclical. This machine PL505 is also produced by the Kharkiv PLINFA plant, it is quite productive, but somewhat loaded constructively, the process is built on mechanical units and therefore has a low level of reliability.

More progressive structures are cutting machines, in which the cutting process is built on a hydraulically actuated drive, which gives a number of significant advantages. First of all, it has high specific power and productivity, small dimensions and high reliability that enables them to be implemented in production lines of small enterprises.

Fig. 2: PL505 Continuous Cutting Machine

1.1 Analysis If Recent Studies and Publications

The proposed version of the modernization of the link of the bricks of the existing production line proposed by the authors is to replace the mechanical construction on the device based on the hydroautomatics [1], built on the principle of the mechatronic system. The basic functional diagram of the device is presented in Fig. 3.

Equipment works as follows. As the clay beam 10 passes, the sensor 9 calculates the size of the n-th amount of the bricks (depending on the number of cutting members 12) and provides an electrical signal to the control unit 7.

The latter generates control signals for the hydraulic control equipment - the safety-overflow valve 1b and the distributors 2 and 6. The valve 1b switches from the position of "unloading the pumping station" to the operating mode - when the pressure in the hydrosystem increases and the flow of the working fluid from the pumping station is sent through the corresponding position of the distributor 2 and 6 to the actuator Drill cylinders 3 and 4. Hydraulic cylinder 3 moves the cutting member (traverse 11 with cutting elements 12) to form the bricks, and the hydraulic cylinder 4 simultaneously provides synchronization of the motion of the base of the entire structure 13, which is located on the rolling bearings 14, with the movement of clay beam 10. Such a scheme of motion provides a lack of relative movement between the executive cutting organs and clay bar, which guarantees the correct geometry of the samples of the brick during its cutting.

In the control system of the equipment under consideration, the possibilities of adaptive control of the technological process are laid down. For this purpose, a controller 7 with an autonomous power supply unit 8 has been introduced into its composition. During the operation, the sensor 9 also measures the speed of the clay beam, which is analyzed by the controller 7, which in turn generates control signals to the control unit for the amount of charge of the pump station 1 and the regulator flow with proportional control 5. Thus, the control system provides a change in the speed of movement of the main executive equipment of the equipment, depending on the change in the rate of feeding the clay beam into the zone of forming it on separate bricks.

Examples of the study of the dynamics of such systems can traditionally be work [2], but at a more modern level [3].

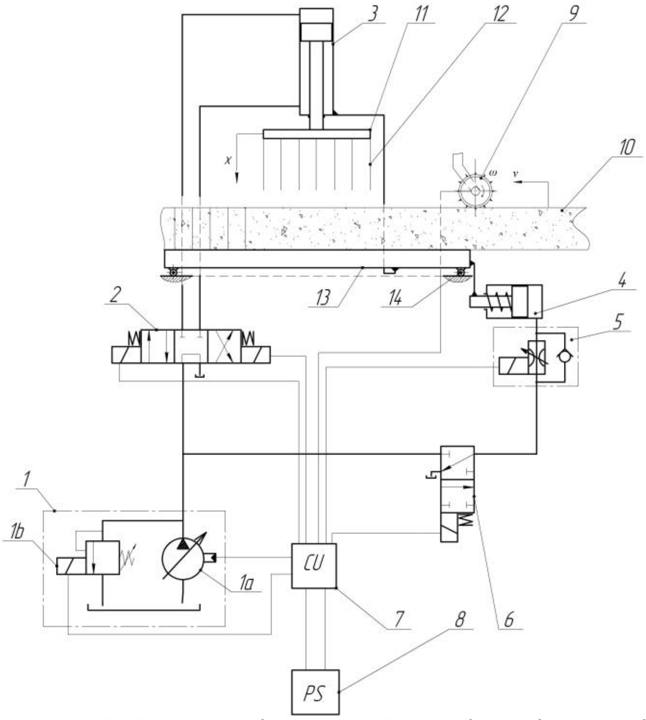


Fig. 3: Hydraulic diagram of an automated device for the formation of bricks

1.2 Statement of the Objective and Tasks of the Study

The main requirement for the drive of the device under consideration is to provide the maximum speed of the cutting body, which provides the correct geometric shape of the brick, and which is associated with the calculation of the power of the pumping station. The given task can be solved by means of mathematical modeling.

2 The Basic Part of the Study

The dynamics of the motion of a cutting device of a device can be represented by a system of differential equations (1), which contains the equation of balance of forces and flows.

$$m\frac{d^2h}{dt^2}+b\frac{dh}{dt}+F_{fr}\left(v,p,p_1,\tau\right)+F_{tech}=p_1\cdot S_1-p_2\cdot S_2 \qquad (1)$$

$$Q_{pump}=Q_{cyl}+Q_{vel}+kW_{pres}\frac{dx}{dt}p+k_{fl.pip}W_{fl.pip}\frac{dp}{dt}$$

$$Q_{vel}=\mu f_{vel}\sqrt{\frac{2(p_1-p_2)}{\rho}}$$

$$Q_{cyl}=S_1\frac{dh}{dt}$$

m, h - respectively, the mass and coordinate of the movement of the cutting body are given; b - coefficient of viscous friction; $F_{fr}(\upsilon, p_1, p_2, \tau)$ - friction force; F_{tech} - technological load; p_1 - pressure of the pumping station; p_2 - pressure of drainage; S_1, S_2 - in accordance, the area of the piston and rod cavity of the hydraulic cylinder; Q_{pump} – consumption of pump station; Q_{vel} - flow through the safety-overflow valve; k - coefficient of fluidity of the working fluid; W_{pres} - volume of pressure pipelines; $k_{fl.pip.}$, $W_{fl.pip.}$- respectively, the coefficient of compliance and the volume of the flexible sleeve, μ - coefficient of expenditure; f_{vel} - the working window of the valve; ρ - the working fluid density.

The frictional force F_{fr} (υ, p_1, p_2, τ) in the balance of power equation represents one of the main negative factors, which directly affects the speed of the movement of the executive cutting equipment. The mathematical interpretation of this magnitude represented a "falling" characteristic [4], depending on the time of the real estate executive.

As part of the equation of the balance of streams component - $k_{fl.pip} W_{fl.pip} \frac{dx}{dt}$ represents the volume of the working fluid, which is used to fill the volume under the deformation of the flexible pipeline, and which significantly affects the dynamics of the movement of the cutting organ [5].

The technological load of F_{tech} arising from the cutting of the clay beam was determined according to Newton's formula as the resistance to the motion of the cutting strand organs in the medium of crude clay density ρ_{clay} at a velocity υ:

$$F_{tech} = C_x \cdot \rho_{clay} \cdot S_x \cdot \upsilon^2 \qquad (2)$$

where, S_x - area of the projection of the body of the cutting organs perpendicular to the direction of motion; ρ_{clay} - density of crude clay; υ - speed of movement of cutting organs; C_x is the coefficient of body resistance in a medium that is a function of the Reynolds number and depends on the shape of the body.

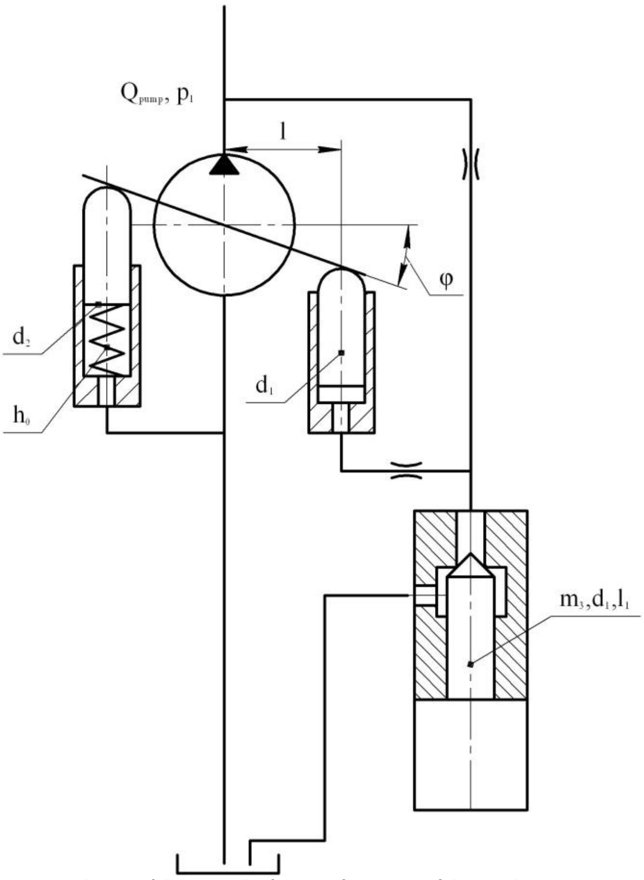


Fig. 4: Scheme of the control of the performance of the axial-piston pump

By setting the maximal allowable time (1secund) to the working motion of a cutting body under the known structure of the device (the length of the movement of the hydraulic cylinder) and solving the system of differential equations relative to the speed of the cutting body, the basic parameters of the pump station are determined. The study of the mathematical model was performed in the MATLAB Simulink environment.

When studying the device for the formation of bricks in the adaptive mode must take into account the process of adjusting the value of the flow Q_{pump} axial-plunger controlled pump (PPS) in accordance with the scheme shown in Fig. 4. The value of the APS charge depends on the position of the vibrational block of the pistons (angle φ) and is described by the formula (3).

Adjustment of the angle φ of the position of the vibrational block of pistons occurs by means of a proportional pressure control valve. Its work is described by the formula (4).

Tracking of the motion of the whole structure of the device, located on a moving platform on the rolling bearings, is provided according to the scheme (see Fig. 5) by an auxiliary hydraulic cylinder whose speed is provided by a special proportional control valve. The work of this system is described by the differential equations (5) and (6).

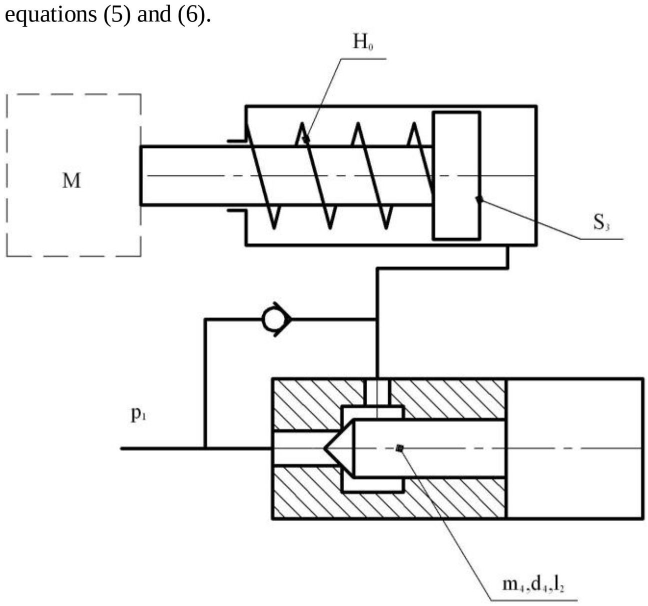


Fig. 5: Scheme of regulation of speed of an auxiliary hydraulic cylinder

$$I\frac{d^2\varphi}{dt^2} = c(h_0 + l \cdot Sin\varphi) \cdot l - p_1 \cdot \frac{\pi d_2^2}{4} \cdot l - \left(\frac{(\pi \cdot \rho \cdot v \cdot d_1 \cdot l_1)}{\varepsilon_0} + \frac{(\pi \cdot \rho \cdot v \cdot d_2 \cdot l_2)}{\varepsilon_0}\right) \cdot l^2 \cdot Cos\varphi \frac{d\varphi}{dt} \qquad (3)$$

$$m_3 \frac{d^2y}{dt^2} = p_1 \cdot \frac{\pi d_3^2}{4} - k_e \cdot I_1 - \frac{(\pi \cdot \rho \cdot v \cdot d_y \cdot l_y)\frac{dy}{dt}}{\varepsilon_y} \qquad (4)$$

$$m_4 \frac{d^2z}{dt^2} = p_1 \cdot \frac{\pi d_4^2}{4} - k_e \cdot I_2 - \frac{(\pi \cdot \rho \cdot v \cdot d_z \cdot l_z)\frac{dz}{dt}}{\varepsilon_z} \qquad (5)$$

$$M\frac{d^2x}{dt^2} + b_1\frac{dx}{dt} + F(v, p_1, \tau) + c_x(H_0 + x) = p_1 \cdot S_2 \qquad (6)$$

where, I, φ is the moment of inertia and the angle of rotation of the piston unit of the APS; d_1, d_2, l_1, l_2 - respectively, the diameters of the hydraulic cylinders and shoulders of the moment of rotation of the tilting drive of the block of pistons; p_1 - pressure at the pressure line: I_1, I_2 - value of current in the networks of control of proportional valves; y, z - coordinates of movement of shutters of valves with proportional control, respectively, in the schemes of regulation of the efficiency of the APS and the speed of the auxiliary hydraulic cylinder; d_3, d_4, m_3, m_4, respectively, the diameters and the weight of gate valves with proportional control, respectively, in the control systems for the efficiency of the APS and the speed of the auxiliary cylinder; k_e is the coefficient of proportionality of the electromagnet; h_0, c - respectively, preliminary compression and stiffness of the spring in the scheme of adjustment of the productivity of the APS; H_0, c_x - respectively, preliminary compression and stiffness of the spring of the rod cavity of the auxiliary cylinder; M - the mass of the moving part of the equipment device connected to the auxiliary hydraulic cylinder is given; b_1, F_{fr} (υ, p_1, τ) - respectively, damping factor and frictional force in the auxiliary hydraulic cylinder; l_y, l_z, ε_y, ε_z - respectively, the length of the contact and the gap between the gate valves and the regulator housing with proportional control.

3 Results and Discussion

As a result of the research, the dependence of influence is most determined weighty factors on the dynamics of movement of the working bodies of the device for the formation of raw bricks (diagram 6,7,8).

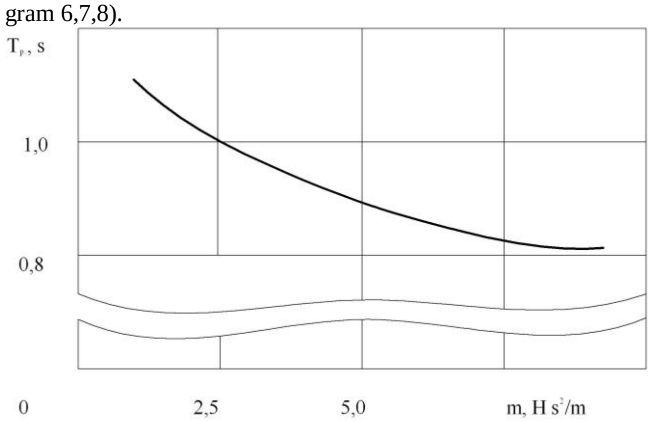


Fig. 6: Impact on the duration of the T_p of the working cycle of the mass m of the moving bodies of the cutting device

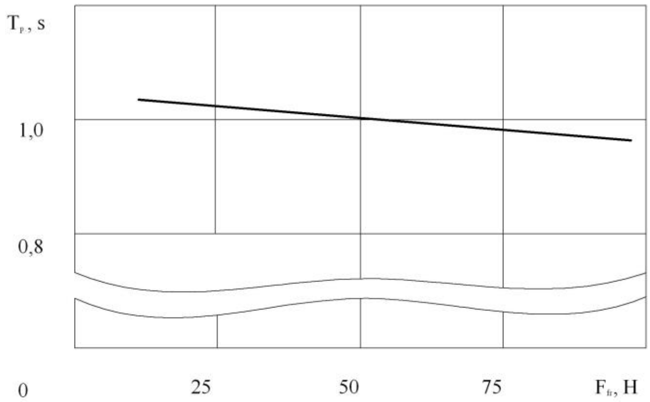


Fig. 7: Effect on the duration of the T_p of the working cycle of the frictional forces F_{fr} during the movement of the cutting device organs

These factors have appeared - the mass m (generally inertia) of the moving parts of the cutting body is given; technological load F_{tech}; Friction F_{fr}. which occurs in the process of movement of the cutting device organs; the hydraulic stiffness of the pressure manifold of the pumping station is given, taking into account the elastic characteristics of the working fluid $kW_{pres}\frac{dx}{dt}$ and the flexible pressure sleeve $k_{fl.pip}W_{fl.pip}\frac{dx}{dt}$.

The influence of F_{tech} technological load on the dynamics of the working cycle of equipment for the formation of bricks was insignificant.

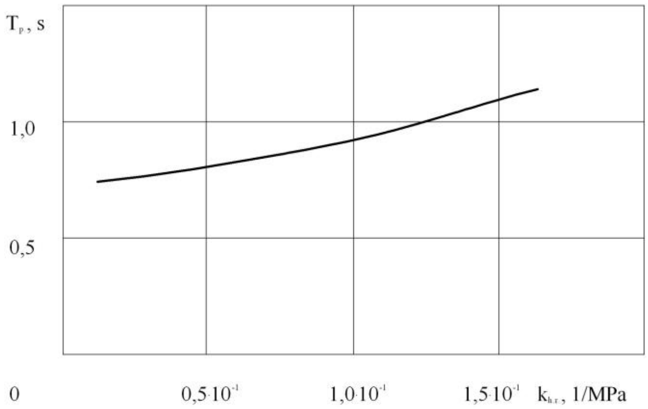
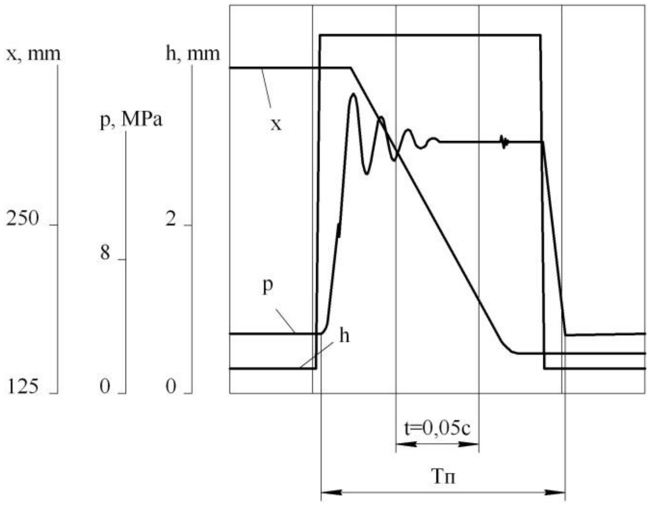
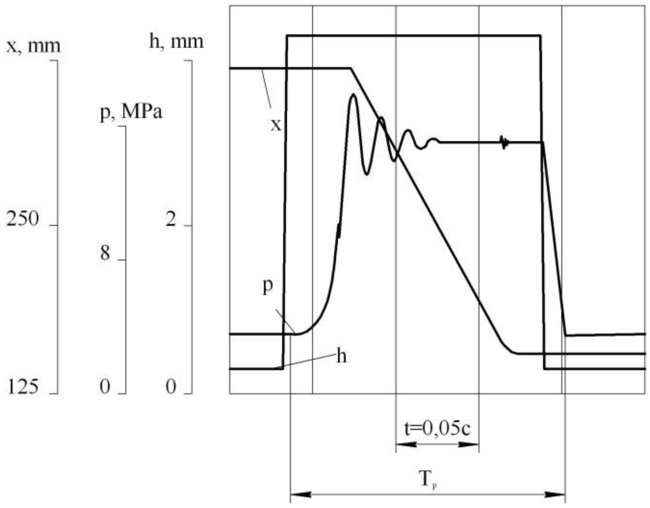


Fig. 8: Impact on Duration T_p of the working cycle of the reduced hydraulic rigidity $k_{h.r.}$ of the pressure line of the pumping station



a



b

Fig. 9: Samples of oscillograms of the transition process of the working motion of the cutting device, taking into account the coefficient of compliance of the $k_{fl.pip}$ of the flexible sleeve of the dynamic $E_{d.fl.pip}$ (a) and the static $E_{s.fl.pip}$ (b) of the elastic modulus. Denomination: x - coordinate of movement of the cutting device of the device; p - pressure in the pressure line of the pumping station; h - coordinate of the spool movement of a 3-position distributor.

Also, as a result of the study of the mathematical model of the equipment, transient processes of the working cycle were obtained. Samples of such oscillograms are presented in Fig. 9

The analysis of the submitted oscillograms shows that the beginning of the movement of the main hydraulic cylinder (coordinate

x) has a significant delay after the switch of the spool of the main distributor (coordinate h) and occurs only after a certain value of pressure (coordinate p) has been obtained at the pressure line.

At the same time there is a overregulation according to the pressure value relative to the nominal value, which is connected with the tolerance of the pressure line and the need to create excessive effort to overcome the forces of inertia and initial friction at the time of the shift of the rod of the main hydraulic cylinder.

4. Conclusion

As a result of the conducted research it was established that for the technological equipment with a 7-point cutting body, which is driven by a cylinder with a diameter of a 50 mm piston and a 250 mm working stroke, the required power of the pumping station is 4,0 kW at a minimum consumption of 20 l/min and a nominal pressure of 16,0 MPa.

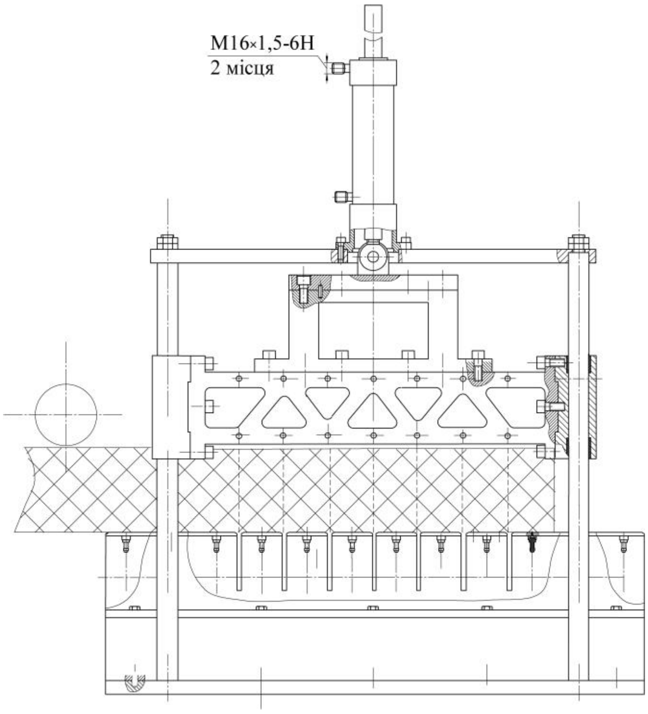


Fig. 10: Principle diagram of the design of equipment for the formation of raw bricks.

On the basis of the obtained researches and calculations, a constructive scheme of the device was developed, which takes into account the influence of the most important factors on the dynamics of movement of the executive bodies of the device - the mass of moving parts of the executive body, the friction forces in the guides, the geometric parameters of the flexible arm of high pressure, etc. are given. (see fig. 10).

A test piece of upgraded equipment is tested in real production conditions with a positive result (see Fig. 11).

Fig. 11: General view of the modernized technological equipment for the formation of brick during installation work in a real enterprise.

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