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CALCULATION OF PARAMETERS OF HYDRAULIC CONE CRUSHER

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РАСЧЕТ ПАРАМЕТРОВ ГИДРОФИЦИРОВАННОЙ КОНУСНОЙ ДРОБИЛКИ

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The paper gives an analysis of implementation of hydropneumatic accumulators that provide significant reduce of energy consumption work processes and increase performance of mining machines, in particular cone crushers. A method that allows passing a body that is not to be crushed through a crushing chamber of a cone crusher with hydraulic cylinders and hydropneumatic accumulators is given. The system that presses crushing bowl to a frame is described. A system of hydraulic unloading from non-crushing bodies and blockages is presented. A basic hydraulic scheme of pressing system is proposed. The paper gives a description of mechanism that creates work pressure inside hydropneumatic accumulator. Parameters of hydraulic cylinders and hydraulic accumulators are determined. The crushing force is set by dimensions of hydraulic cylinders and pressure of work fluid in hydropneumatic accumulator. When a non-breaking body enters a crushing chamber a movable cone moves an armor of a bowl with support and control rings and associated elements. An example of calculation is given. Calculations are necessary to design a new hydraulic unit that control discharge slot of a cone crusher. A method for determination of geometric parameters of crushing chamber when passing a non-crushing body is given. Calculation of power parameters of hydraulic system of a cone crusher including hydraulic cylinders and hydropneumatic accumulators is proposed. The method can be applied in design departments of mining and industrial enterprises while design of cone crushers. A proposed hydraulic scheme with throttle installation will reduce speed of fluid flow when unloading a hydraulic accumulator. That will reduce impact of accumulator piston and foaming of liquid in a tank.

Ключевые слова:
конусная дробилка, камера дробления, пропуск недробимого тела, модель, гидроцилиндр, гидроаккумулятор, давление, расчет, рабочая жидкость.

Приведена оценка применения гидропневмоаккумуляторов, обеспечивающих существенное снижение энергоемкости рабочих процессов и повышение производительности горных машин, в частности конусных дробилок. Охарактеризована методика расчета параметров при пропуске недробимого тела через камеру дробления конусной дробилки с гидроцилиндрами и пневмогидроаккумуляторами. Описана система прижатия дробильной чаши к станине. Показана система гидравлической разгрузки от недробимых тел и завалов. Предложена принципиальная гидравлическая схема системы прижатия. Приведено описание доведения давления в гидропневмоаккумуляторе до рабочего. Дано описание процесса поджатия и разгрузки чаши. Определены параметры гидроцилиндров и гидроаккумуляторов. Усилие дробления задается размерами гидроцилиндров и давлением рабочей жидкости в гидропневмоаккумуляторе. При попадании недробимого тела в камеру дробления подвижный конус перемещает броню чаши с опорным и регулирующим кольцами, а также связанные с ними элементы. Приведен пример расчета. Расчеты необходимы для проектирования нового гидрофицированного узла регулирования разгрузочной щели конусной дробилки. Предложены методика определения геометрических параметров камеры дробления при пропуске недробимого тела и расчет силовых параметров гидравлической системы конусной дробилки, включающей гидроцилиндры и пневмогидроаккумуляторы. Методика может быть применена в конструкторских отделах горно-промышленных предприятий при проектировании конусных дробилок. Предложенная гидравлическая схема с установкой дросселя позволит уменьшить скорость течения жидкости при разгрузке гидроаккумулятора, что снизит удары поршня аккумулятора и вспенивание жидкости в баке.

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Introduction

Crushing of rock in a cone crusher is carried out by grinding pieces of rock in a crushing chamber formed by an armor of a cone and bowl. An eccentric sleeve which is rotated by a drive provides oscillation of a cone along spherical bearing surface of raduis R and change volume of a chamber [1–13].

For workflow description a design model is usually represented by a vertical cross section (Fig. 1). There are a closed position of a crushing chamber on the left of a model

and open position on the right. If eccentric is turned there is movement of an armor and decrease of crushing chamber. A chamber is switched then from an open to closed position.

Crushing force is set by size of hydraulic cylinders 7 and work fluid pressure in the hydraulic accumulator 8. Hydraulic accumulators are permanently connected to a working chamber of a hydraulic cylinder and provide required force to press a support ring to a crusher body. Calculation of parameters at normal crushing regime is given in [14].
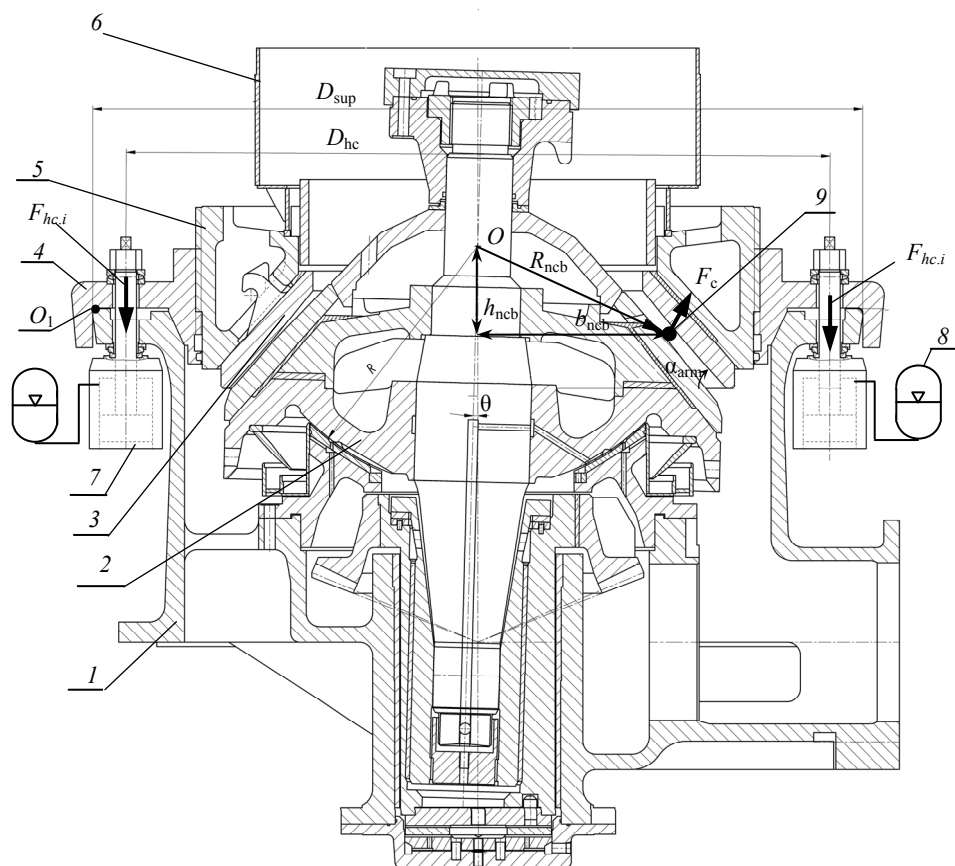

Fig. 1. A model for calculation of parameters: *1* – shell of crusher; *2* – cone; *3* – armor of a bowl; *4* – support ring; *5* – control ring; *6* – load part; *7* – hydraulic cylinders; *8* – hydropneumatic accumulators; *9* – non-crushing body; D_{sup} – diameter of a support ring; D_{hc} – diameter of position of rods of hydraulic cylinders; R_{ncb} radius from a point of suspension to non-crushing body; O – conditional suspension point (center of curvature of bearing surface of a cone); O_1 – turning point of a support ring; $F_{hc.i}$ – force on i rod of a hydraulic cylinder; F_c – force transmitted through a non-crushing body from a cone to an armor of a bowl; γ – nutation angle

When a non-crushing body enters a crushing chamber a movable cone moves an armor of a bowl with support and control rings, as well as

associated elements. A support ring moves by turning with respect to a point O_1. When a support ring is rotated, hydraulic cylinder rods move and

displace volume of liquid in hydraulic accumulators. Pressure increases if fluid is added into accumulator. Movement of rods depends on the size of a non-crushing body and its position in a crushing chamber.

Description of pressing system workflow [19]

A crushing bowl is pressed to frame by rod chambers of hydraulic cylinders. Each hydraulic cylinder is connected to its accumulator. Set the initial pressure of gas in accumulator, which maintain the pressure in a chain of hydraulic cylinders after disconnection of a hydraulic unit pump.

If a non-crushing body with a width of value larger than an unloading slot on closed side, but less than width of unloading slot on an open side enters a crushing chamber, it must pass it without stopping. That is called amortization, i.e. one-side lift of crushing bowl. In this case, the stroke of all the pistons will be proportional to a projection of distance from a hydraulic cylinder to a turning point of a crushing bowl relative to a frame (the largest move from a side of non-crushing body) on the axis "non-crushing body – turning point". During a lift of a crushing bowl, some oil is displaced from hydraulic cylinders into hydropneumatic accumulators by the force of a crushing cone (Fig. 2). Then, after amortization it moves back under the influence of overpressure inside of accumulators.

If a non-crushing body with a width greater than width of unloading slot on an open side enters crushing chamber then there are several cycles of amortization with a clamped non-crushing body. The main drive is overloaded and after several cycles of overload should stop. In case a drive is stoped due to its overload from amortization system triggered a system has to be unloaded through draining oil in a tank of a hydraulic unit.

In the event of oil leakage, i.e. when pressure in a chain of hydraulic cylinders falls to the set pressure, a pressure switch must turn on a pump and restore pressure, after which a pump is switched off. If pressure inside of hydraulic cylinders is not automatically restored and falls below the set value, a pressure switch must be triggered, which will give a signal to turn off the main drive. A red low-pressure warning light is on. A crusher can not be operated in such state.
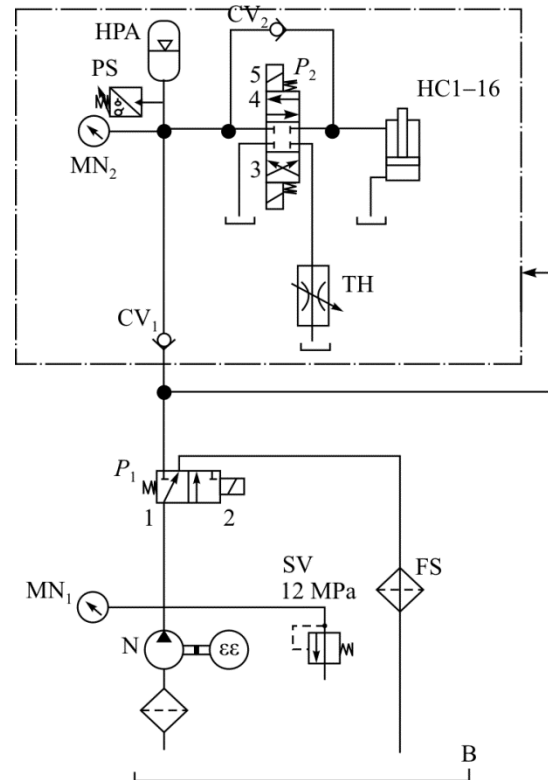

Fig. 2. The basic hydraulic scheme of a system that press a crushing bowl to a frame

A system of hydraulic unloading from non-crushing bodies and blockages [19]

When a crusher stops under force due to the fact that a large non-crushing body enters a chamber or due to power shutdown or power overload, a crushing chamber is filled up with crushing material. To clean a crushing chamber from a blockage or a non-crushing body it is necessary to do following actions: to depressurize hydraulic cylinders that press a crushing bowl; pump pressure to a piston chamber of unloading hydraulic jacks from non-crushing bodies; lift a crushing bowl to a certain height; after a crushing chamber is unloaded lower a crushing bowl to work position by pumping pressure to rod chamber of hydraulic jacks; restore the force that press a bowl by creating working pressure in rod chambers of hydraulic cylinders of bowl pressing.

The proposed basic hydraulic scheme of pressing system is presented on the Fig. 2 (positive decision on the application No. 2015151506).

A hydropneumatic accumulator accumulator (HPA) is charged with nitrogen in advance.

Bringing the pressure inside hydropneumatic accumulator HPA to work one. A hydraulic distributor P_1 is switched to position 2, liquid from a pump H is directed through back-pressure valves CV_1 to a hydropneumatic accumulator PHA and increases inside pressure to work pressure. When work pressure is acheved a safety valve SV is triggered, a distributor P_1 is switched to position 1 by a control system P_1, a pump H is stoped.

Bowl pressing. Bowl pressing is provided by 16 hydraulic cylinders HC_1-HC_{16} by pressure of liquid supplied to a rod chamber of 16 hydropneumatic accumulators HPA through a hydraulic distributor P_2, located in position 5.

Pass of a non-crushing body. If a non-crushing body enters a chamber a movable cone begins to deflect a bowl. When a bowl turns, hydraulic cylinders (HC) rods begin to move. Liquid from rod chamber is replaced into accumulators PHA through a hydraulic distributor P_2 in position *5*. To avoid an emergency, a check valve CV_2 is installed in parallel to P_2. In case of a non-crushing body enters a chamer liquid goes to PHA through P_2 if due to any reason P_2 is not turned to position *5*. Supply of liquid from HC to HPA leads to pressure increase in it. Wherein, a signal from pressure switch PS hydraulic distributer P_2 switches to middle position *4* and provide a pause to pass a non-crushing body. It happens when a cone starts to move away from a bowl. After a pause, P_2 switches to position *5* again and press a bowl if a non-crushing body is leaved the crushing zone. A pause and switching of distributors are provided by electronic control system.

Bowl unloading. If the pressure in an accumulator after set time interval does not decrease to operating value, i.e. a non-crushing body did not leave crushing zone and a bowl did not lower back to its original position, then a control system generates a signal for switching a hydraulic distributor P_2 to position 3. Liquid from an accumulator goes into a tank. Rod chamber of hydraulic cylinders is connected to a drain system. At the same time, distributors of unloading hydraulic jacks are switched (are not shown in the diagram) and a bowl is lifted. Hydraulic cylinders do not impede lifting because their rod chambers are connected to a drain system. Throttle installation allows reducing flow rate of the fluid when unloading a hydraulic accumulator. That reduces impact of an accumulator piston and foaming of liquid in a tank.

Design of calculation models

Fig. 3 and 4 show calculation models for determination of volume of liquid displaced from each hydraulic accumulator. The designations of parameters and initial data for calculation example are given in Table 1.

The parameters are calculated as follows.

Calculation of geometric parameters. A non-crushing body with a width of d_{ncb} is at distance of h_{ncb} in vertical plane and at b_{ncb} in a horizontal plane from a set point of suspension O. The largest angle that is passed by generator of a cone is equal to double nutation angle θ. When turning a cone lifts an armor of a bowl and associated control and support rings through a non-crushing body. Cone rotation occurs around a conventional suspension point. Rotation of bowl armor and associated elements occures around the reference point O_1.

Distance from conditional suspension point to a non-crushing body

$$L_{Oa} = \sqrt{\left(h_{ncb}^2 + b_{ncb}^2 \right)},$$

where h_{ncb}, b_{ncb} – ddistance from the point of suspension to a non-crushing body along the vertical and horizontal planes respectively.

Section length *ab*

$$L_{ab} = 2L_{Oa} \sin\theta.$$

Horizontal distance from a conventional suspension point to a point of contact of a non-crushing body with bowl armor

$$L_{Ocx} = b_{ncb} + d_{ncb} \sin\alpha_{arm}.$$

Horizontal distance from a point of rotation of a support ring O_1 to a point of contact of a non-crushing body with bowl armor

$$L_{O_1cx} = L_{Ocx} + 0.5D_{sup}.$$

Taking into account small size of a non-crushing body relative to dimensions of a crusher (D_{hc} = 3180 mm, d_{ncb}, mm) it is possible to assume $L_{cd} = L_{ab}$.

Taking this into account an angle of rotation of a support ring relative to a point O_1

$$\beta = 2\mathrm{arctg}\frac{0.5L_{ab}}{L_{O_1cx}}.$$

The maximum stroke of a rod that is the most distant from point O_1 of a hydraulic cylinder is

$$L_{ef} = 2[D_{hc} + 0.5(D_{sup} - D_{hc})\cos\beta].$$

Calculation of distance from the point of rotation of a support ring to a rod oof i HC in horisontal plane with change in $\alpha_{hc.i}$ between horisontal axis x and a line that connects point O and a rod of HC (Fig. 2), from 0 to 2π

$$R_{hc.i.x} = 0.5(D_{sup} - D_{hc}) + 0.5D_{hc} + 0.5D_{hc}\cos\alpha_{hc.i}.$$

Extension of a rod of i hydraulic cylinder $h_{hc.i} = R_{hc.i.x}\sin\beta$.
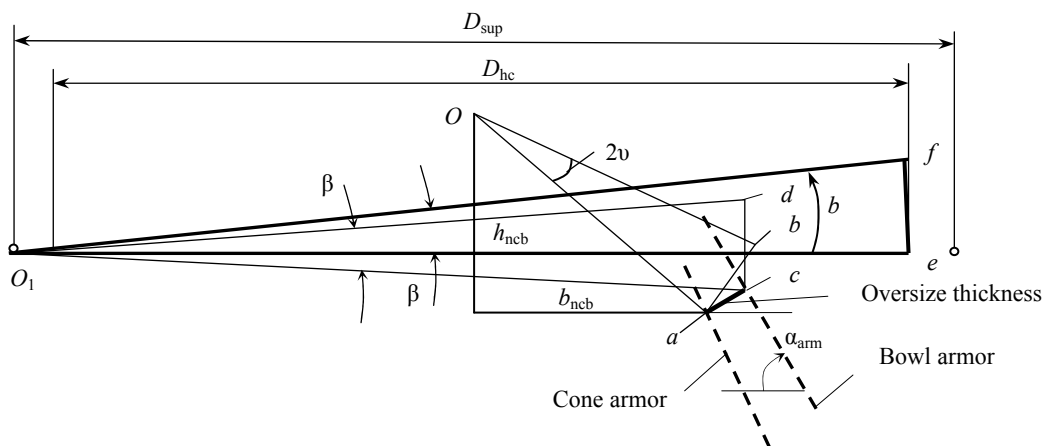

Fig. 3. A scheme for calculation of support ring rotation angle
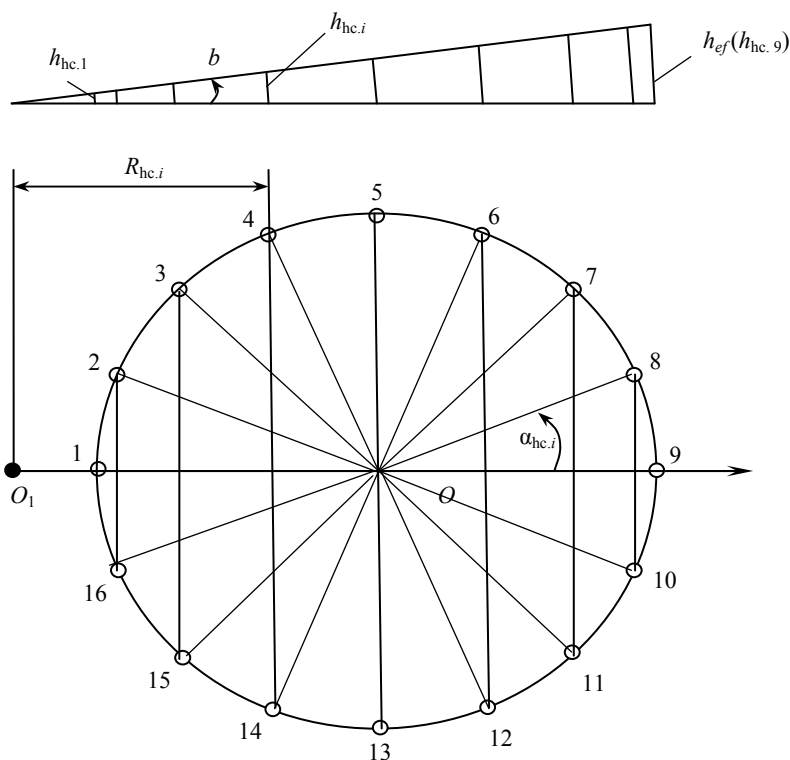

Fig. 4. A scheme for calculation of displacement of rods of hydraulic cylinders

<div align="right">Table 1</div>

<div align="center">Parameters and initial data for calculation</div>

Name	Sign	Value
Nutation angle, degrees	θ	2.1
Thickness of a non-crushing body, mm	d_{ncb}	90
Number of hydraulic cylinders that press a support ring to a frame	N_{hc}	16
Distance between rods of hydraulic cylinders, mm	D_{hc}	3180
Diameter of circle of points of contact of a support ring with a crusher frame when passing a non-crushing body	D_{sup}	3478
Distance from a conventional suspension point to an upper point of crushing chamber:		
vertical	$h_{u.ch}$	190
horizontal	$b_{u.ch}$	660
Distance from a conventional suspension point to a lower point of crushing chamber:		
vertical	$h_{l.ch}$	644
horizontal	$b_{l.ch}$	1100
Angle of tilt of bowl armor to horizon, degree	α_{arm}	50
Crushing force, kN	F_{crush}	7000
Fluid pressure in a hydraulic cylinder for pressing a support ring, MPa	P_{hc}	25
Adjustable maximum pressure in hydraulic accumulator when determining its volume, MPa	P_{max}	30
Reserve volume of liquid in an accumulator for replenishment of volumetric leaks with pressed support ring, l	$V_{r.l}$	0.2
Ratio of rod diameter to hydraulic cylinder diameter	k	0.6

Calculation of force parameters and parameters of a hydraulic system. The crushing force acts perpendicular to a surface of bowl armor. Horizontal component of this force is transferred to a crusher shell. Vertical component of the force must be provided by forces of hydraulic cylinders.

$$F_{crush.horiz} = F_{crush} \cdot \sin \alpha_{crush},$$

$$F_{crush.vert} = F_{crush} \cdot \cos \alpha_{crush}.$$

Force on a rod of i hydraulic cylinder to provide crushing force

$$F_{hc.i} = F_{crush.vert} / N_{hc}.$$

Fluid pressure in a rod chamber of a hydraulic cylinder to provide crushing force

$$P_{hc} = 4 F_{hc.i} / \pi (D^2_{hc} - d^2_{rod}) = \\ = 4 F_{hc.i} / \pi D^2_{hc}(1 - k^2),$$

where D_{hc}, d_{rod} are diameter of piston and rod of hydraulic cylinder.

According to adjusted pressure

$$D_{hc} = \sqrt{\frac{4F_{hc.i}}{\pi P_{hc}(1 - k^2)}}.$$

Calculation of parameters of accumulators [15-20]:

$$V_l = V_{r.l} + L_{ef} \pi (D^2_{hc} - d^2_{rod}) / 4,$$

where $V_{r.l}$ is reserve volume of liquid in an accumulator to compensate volumetric leaks with a pressed support ring.

Design volume of an accumulator will be

$$\frac{V_l}{V_c} = \left(1 - \frac{P_{hc}}{P_{max}}\right),$$

where P_{max} is set maximum pressure in an accumulator when determining its volume.

Considering the value of the maximum pressure it is possible to determine design volume of an accumulator

$$V_c = \frac{V_l}{\left(1 - \dfrac{P_{hc}}{P_{max}}\right)}.$$

Pressure in an accumulator when its liquid volume changes

$$P_{hc.i} = P_{hc} \frac{V_c - V_{r.l}}{V_c - (V_{r.l} + V_{l.i})},$$

where $V_{l.i}$ – liquid volume supplied by i hydraulic cylinder when its rod is displaced by support ring turning, $V_{l.i} = h_{hc.i} \pi (D^2_{hc} - d^2_{rod}) / 4$.

The force created by i hydraulic cylinder,

$$F_{hc.i} = P_{hc.i} \pi (D^2_{hc} - d^2_{rod}) / 4.$$

Total force of hydraulic cylinders applied to a support ring

$$F_{\text{hc.tot}} = \sum_{i=1}^{N_{\text{hc}}} F_{\text{hc}.i}.$$

Total torque with respect to a point O_1 during rotation of a support ring

$$M_{\text{hc.tot}} = \sum_{i=1}^{N_{\text{hc}}} F_{\text{hc}.i} \cdot R_{\text{hc}.i.x}.$$

Position of resultant forces of hydraulic cylinders $F_{\text{hc.tot}}$ in respect to a point O_1

$$X_{\text{hc.tot}} = M_{\text{hc.tot}} / F_{\text{hc.tot}}.$$

Armor force at a point of location of a non-crushing body in accordance with a condition of static equilibrium of a torque that hold a hydrocylinder and torque from a vertical component of a crushing force

$$M_{\text{hc.tot}} = F_{\text{cruch}} \cos \alpha_{\text{cruch}} \cdot b_{\text{ncb}},$$

from which

$$F_{\text{cruch}} = \frac{M_{\text{hc.tot}}}{\cos \alpha_{\text{cruch}} \cdot b_{\text{ncb}}}.$$

In fact, there is a greater (by the coefficient of dynamics) force on a non-crushing body.

Example of calculation

Table 2

Calculation of maximum displacement of a hydraulic cylinder rod

h_{ncb}	b_{ncb}	L_{Oa}	L_{ab}	L_{ocx}	L_{O1cx}	β, deg.	L_{ef}
190	660	687	50.3	729	2468	0.0204	67.9
240	707	746	54.7	776	2515	0.0218	72.4
291	753	808	59.2	822	2561	0.0231	76.9
341	800	870	63.7	869	2608	0.0244	81.4
392	847	933	68.4	916	2655	0.0258	85.7
442	893	997	73.0	962	2701	0.027	90.0
493	940	1061	77.8	1009	2748	0.0283	94.2
543	987	1126	82.5	1056	2795	0.0295	98.3
594	1033	1192	87.3	1102	2841	0.0307	102.3
644	1080	1257	92.1	1149	2888	0.0319	106.2

Table 3

Force parameters and parameters of a hydraulic system

Name of parameter	Value
Horizontal component of a crushing force, kN	5362
Vertical component of a crushing force, kN	4500
Force applied to a rod of i hydraulic cylinder to provide a crushing force	281,24
Diameter of a piston of hydraulic cylinder, mm	150
Diameter of a rod of hydraulic cylinder, mm	90
Liquid volume entering an accumulator with maximum displacement of a rod, l	1,4
Design volume of an accumulator, l	8,4

Table 4

Calculation of extension of rods of hydraulic cylinders when a non-crushing body is in the lower part of a crushing chamber

Parameter sign	Number of hydraulic cylinder in accordance with Fig. 2								
	1	2, 16	3, 15	4, 14	5, 13	6, 12	7, 11	8, 10	9
$\alpha_{hc.i}$	180	157.5	135	112.5	90	67.5	45	22.5	0
$R_{hc.i}$	149	270	615	1131	1739	2348	2863	3208	3329
$h_{hc.i}$	4.8	8.6	19.6	36.1	55.5	74.9	91.3	102.3	106.2
$V_{l.i}$, l	0.05	0.10	0.22	0.41	0.63	0.85	1.03	1.16	1.20
$P_{hc.i}$	25.17	25.3	25.73	26.38	27.19	28.04	28.81	29.35	29.55
$F_{hc.i}$, kN	284.6	286.2	290.9	298.2	307.3	317.0	325.7	331.8	334.0
$M_{hc.i}$, kNm	42.4	77.3	178.8	337.1	534.4	744.1	932.6	1064.4	1111.9
Coefficient of pressure increase $k = P_{hc.i}/P_{hc}$	1.007	1.013	1.029	1.055	1.087	1.122	1.153	1.174	1.182

Table 5

Force parameters of a crusher

Name of parameter	Value
Total force of hydraulic cylinders applied to a support ring, kN	2775.5
Total torque relative to a point O_1 when a support ring is rotated, kNm	5023.2
Position of resultant forces of hydraulic cylinders $F_{hc.tot}$ from a point O_1, mm	1810
Force applied to a point of contact of a non-crushing body, kN	7235

Conclusion

The method of determination of geometric parameters of a crushing chamber during passing of a non-crushing body is proposed. Calculation of force parameters of a hydraulic system of a cone crusher including hydraulic cylinders and hydropneumatic accumulators is proposed. The method can be applied in design departments of mining and industrial enterprises during design of cone crushers.

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