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DESIGN OF THE CENTRIFUGAL-GYRATORY MILL OF MINING PRODUCTION

Abstract. To provide the mining enterprises of Kazakhstan with a new type of mill, which has a reduced power consumption. Mining mills are the main consumers of electricity in the mining sector, so the task of reducing energy is very important. Centrifugal-gyratory mills are designed for grinding various mineral raw materials. Mills of this type have been known for a long time and have shown good results in the process, one of the main advantages of these mills is the reduced consumption of electric energy. In operational tests of this scheme, its main drawback was found to be a high probability of a driven crankshaft motion according to the unplanned law of motion, which leads to a breakdown of the mechanism. Even a small inaccuracy in the manufacture of the mechanism, backlash can lead to a gap of the driven crank with the leader, especially in the zone close to the extreme position.

In this paper, the design of the centrifugal-gyratory mill based on a rocking mechanism is studied. The mill has several advantages over analogues: simplification of design, high dynamic stability, energy costs reduced by 2 times, etc.

For the first time, operational testing of mills was carried out at the Scientific Research Institute of Mineral Processing of the National Center for Processing Mineral Resources of the Republic of Kazakhstan. The working principle of the mill is studied, which consists in a plane-parallel displacement of cylindrical grinding chambers - tubes in a plane perpendicular to their axis, at which each point of the grinding chamber moves along a circle with a radius equal to the length of the crank r of the mill mechanism [5]. The centrifugal force of the counterweights, the unbalanced dynamic force and moments, the force analysis are calculated.

Results. It can be seen from the research results that the proposed mills have a specific capacity index of 140 kg/kW or 8 kW/ton of production. According to this indicator, the proposed mills exceed the ball mills by 2 times [3]. In this scheme, the theoretical balance of the mechanism is obtained. There are significant design achievements: there is one crankshaft, there is no excessive bonds, no need for gears, which greatly simplifies the design. The mill has high maintainability.

Scientific novelty. The novelty of the results is the creation of centrifugal-gyratory mill constructions, which provide the optimum grinding process, energy intensity, metal consumption and mill productivity.

Practical significance. Based on calculations and experimental data, as well as in determining its rational design and technological parameters, it was revealed that in the process of the experimental-industrial period of the mill at the polygon of the State Research and Production Association of Industrial Ecology "Kazmekhanobr" (Almaty), which is part of the National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan, that the mill has a low level of metal consumption, it has a low level of complexity structure, thereby reducing the cost of the mill compared with the ball ones approximately in 3 times, compared with existing centrifugal mills in 1.5 times. Tests of the mills showed their economy in energy consumption, which is the most important indicator.

Keywords: centrifugal-gyratory mill, grinding, mineral raw materials, metal consumption, energy intensity, design, productivity, milling, crank.

Centrifugal mills have a high level of grinding of raw materials at relatively low energy costs. Currently, existing centrifugal planetary mills are characterized by high complexity of construction and high cost. The developed new design of the centrifugal-gyratory mill also has a high complexity of construction and dynamic imbalance, which leads to rapid wear.

The author proposes a new design for the vibrator drive of such a mill, which is much simpler than analogues, it is dynamically well balanced, as a result of which the mill has a low level of vibration and low wear during operation. Low energy costs are explained by the use of centrifugal force of grinding bodies oscillations when milling. Getting such a force requires a much lower energy consumption than the use of the force of gravity used in ball mills or the compression forces of rolls in roller mills.

The principle of operation of such a mill consists in a plane-parallel displacement of cylindrical grinding chambers - tubes in the plane perpendicular to their axis, in which each point of the grinding chamber move-s along a circle with a radius equal to the length of the crank r of the mill mechanism (figure 1).

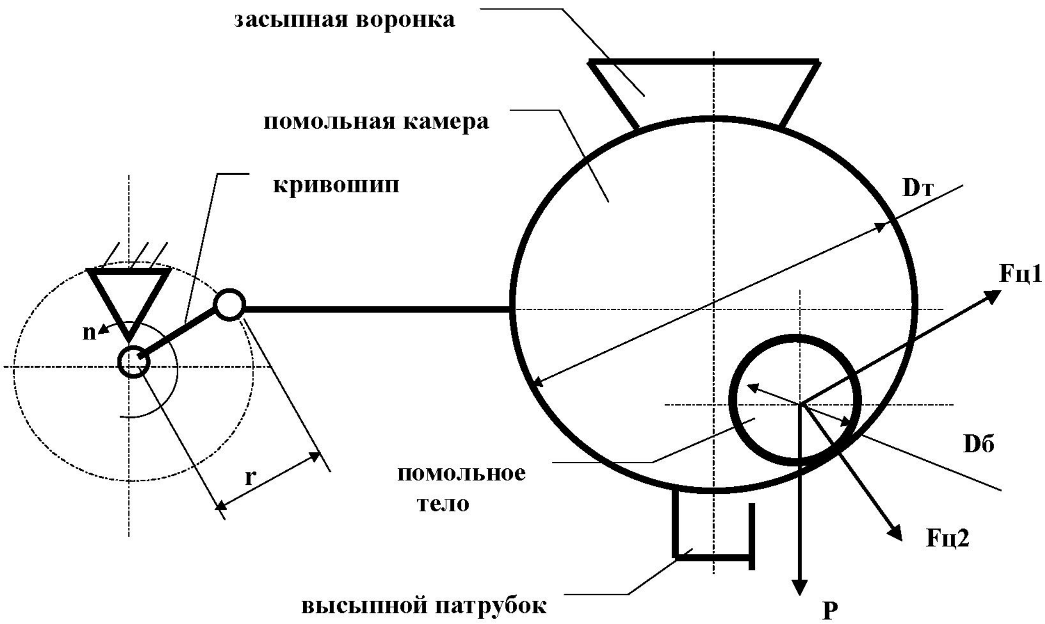


Figure 1 – Motion scheme of one grinding body in the grinding chamber

The plane-parallel displacement of the grinding chamber allows the hopper to be kept at the top all the time, and the discharge nozzle is at the bottom, which creates a great convenience for backfilling the raw materials and unloading the finished product from the grinding chamber. Such movement of the grinding chambers creates a sufficiently strong and vigorous mixing of the cylindrical grinding bodies in the grinding chamber.

Let us consider the motion of a single cylindrical grinding body with mass m and diameter $D_б$ in the grinding chamber-tube with a diameter $D_т$ when the crank is rotated with radius *r* at a frequency *n* (figure 1). When rotating the crank on the grinding body, the following applies: 1. The gravity P=mg, directed always downwards. 2. Centrifugal force $F_{ц1} = mr\,(\pi n/30)^2$, which is parallel to the crank position and rotates together with the crank in the same direction with the same frequency *n*. Under the action of this force, the grinding body begins to move along the inner surface of the grinding chamber-tube. The motion occurs along a circle with $R_к = (D_т – D_б)/2$ in the same direction as the rotation of the crank. The force $F_{ц1}$ is directed along the tangent to the circumference of the motion of the grinding body. In this motion, the second centrifugal force $F_{ц2}$ appears, which is directed along the radius of the grinding chamber-tube, its value is $F_{ц2} = mR_к\,(\pi n/30)^2$. This force always presses the grinding body against the wall of the grinding chamber-tube. From these considerations, it is clear that the grinding body in the general case has three forces. All these forces are involved in the grinding of raw materials entering the grinding chamber. Forces P and $F_{ц2}$ press the raw materials, and the force $F_{ц1}$ breaks the raw material, we have a combined effect on the product of the grinding.

Let us consider the interaction of several identical grinding bodies in the grinding chamber (figure 2). It can be seen from the figure that the force $F_{ц1}$ and the gravity P act on all the grinding bodies. The grinding bodies occupy different positions in the tube of the grinding chamber, therefore only one body can occupy such an arrangement when its force $F_{ц1}$ is directed to the circumference of the movement, and only for this body, it is a completely moving force. In figure 2, this is the body 3. For the remaining bodies, the force $F_{ц1}$ is partially moving, this body is 2, which does not have a moving value, the body 4, the opposing motion, the body 1. In this case, it turns out that only one grinding body is fully driven, acts as the engine of the entire system of grinding bodies. Some bodies help it in this action, some counteract. Naturally, the rotation of the entire grinding body system occurs at a frequency n_1 much inferior in frequency n, because in this case there is an opposition to certain bodies. If the values of the rotation frequencies do not coincide, all grinding bodies of the system are in the role of the engine of the entire system in order. In this case, the forces in the system are equal: $P = mg$; $F_{ц1} = mr\,(\pi n/30)^2$; $F_{ц2} = mR\kappa\,(\pi n_1/30)^2$. Since the forces $F_{ц2}$ are aimed in different directions, their vector sum is small, and in practical calculations, their influence on the equilibrium of the mill is not taken into account.

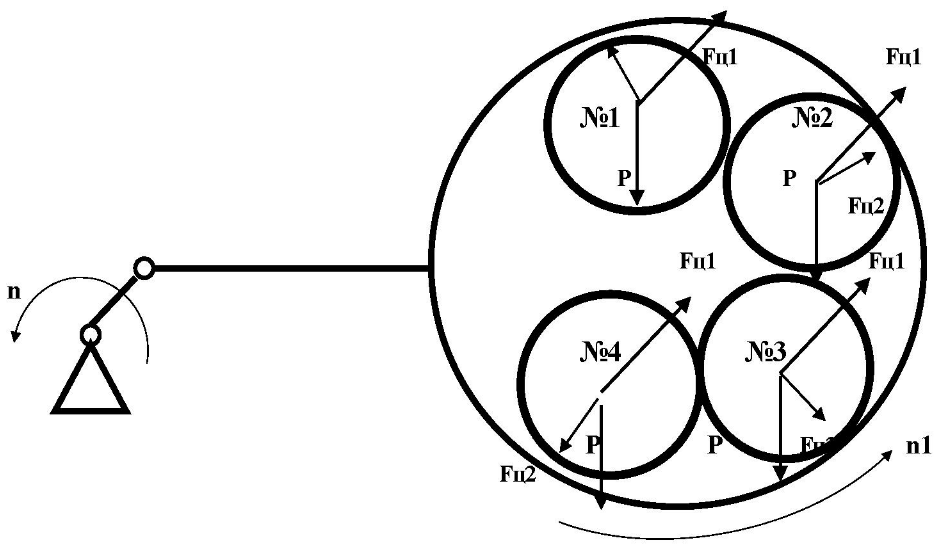


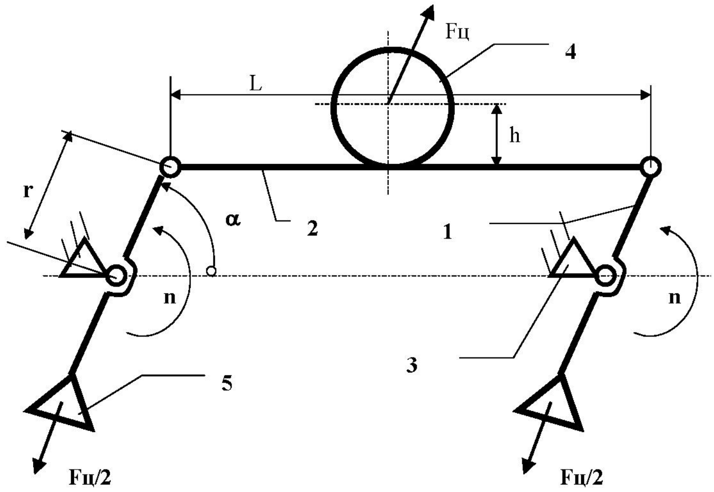
Figure 2 – Motion scheme of several grinding bodies in the grinding chamber

For the successful operation of the grinding body system, it is very important to ensure their movement with pressure against the tube walls, but taking into account the fact that $n_1 \ll n$, as well as the resistance of the raw materials in the grinding chamber contributes to the decrease in the value of n_1, the condition of constant clamping of the bodies to the walls of the tube is not always satisfied, especially during the passage of the upper point. In this case, it should be ensured that the upper grinding body cannot fall to the center of the tube, which instantly will absorb the entire rhythm of movement of the grinding bodies. This can be achieved by selecting geometric parameters - $D_б$, $D_т$ and the number of grinding bodies - N. From practical experiments it is seen that the optimal value of N=4, with N=3 in the grinding chamber, there is too much free space, with N=5, while ensuring that all grinding bodies are pressed against the tube wall, too much space is also released in the center of the tube. It also follows from the experiments to choose the parameters $D_б$ and $D_т$ from the following ratio $D_т/D_б = 2.6 - 2.7$.

Currently, there is a basic design of the mill, working on this principle. The scheme of this mill has a number of significant disadvantages that prevent the widespread use of mills of a similar type. These are a dynamic imbalance of the mill, a large metal capacity of the structure, its complexity and cost. The diagram of this mill is shown in figure 3. It consists of two identical cranks 1, connected by connecting rod-driver 2, which together with the rack 3 constitute the parallelogram. The rod 2 has the grinding chamber 4. Cranks 1 have counterweights 5.

To fully balance the mechanism, it is necessary that the vector sum of all the static forces applied to the mechanism (1), the sum of the twisting moments of these forces (2), the vector sum of all the dynamic

Figure 3 –
Scheme of the basic design of the mill



forces (3) and the sum of the torques of these forces (4) would be equal to zero, that is the condition would be satisfied:

$$\Sigma Pi = 0; \quad (1)$$

$$\Sigma Mi = 0; \quad (2)$$

$$\Sigma Fqi = 0; \quad (3)$$

$$\Sigma Mqi = 0. \quad (4)$$

In the above scheme, condition (4) is not always satisfied. When the condition (3) is fulfilled, the centrifugal force of the grinding chamber $F_ц$ is to be equalized by the centrifugal forces of the two counterweights, hence the force of one counterweight is $F_ц/2$. The grinding chamber 4 is installed in the center of the rod 2, the length of which is equal to L. The center of gravity of the grinding chamber 4 in this circuit is always raised to the value h relative to the rod line. This is dictated by design requirements. The condition (4) for this scheme is as follows:

$$(F_ц/2)\, L * \sin\alpha - F_ц\, ((L/2) * \sin\alpha + h * \cos\alpha) = 0$$

This equation will be zero only if $h = 0$ or $\alpha = 90^0$ or 270^0.

Dynamic unbalance of the mill contributes to the appearance of the strong vibration during operation, which leads to its rapid destruction. It should also be noted that the considered scheme has an excessive connection, which also leads to the appearance of vibration, complicates the manufacture of the mill and its assembly. Cranks 1 are driven into rotation by means of a gear reducer, cranks rotate in one direction at a time. The presence of two parallel kinematic chains determines the presence of an excessive bond.

Let us consider the principle of the drive of the new mill. The engine 1 (figure 4) rotates the shaft 3 through the reduction gear 2, the cranks 4 and 7 rotate with it. The crank 4 rotates the driver 5 together with the grinding chambers 6. The crank 7, interacting with the groove 10 of the lever 9, causes the latter to perform the oscillatory motion. Lever 9 works like a link. The other end of the lever 9 also oscillates with the finger 12. The mechanism parameters are adjusted so that the axis of the finger 12 is always in line with the vertical axis of the groove 13, which in this case can only move vertically relative to the finger 12. Since the groove 13 is part of the driver 5, the driver 5, making a rotation along with the crank 4, all the time retains its parallelity with respect to the horizontal, that is, it performs a plane-parallel motion. Grinding chambers 6 also move with them.

This scheme has no excessive bonds, is dynamically balanced, does not require the use of gear wheels, is structurally simple.

Parameter	Basic version	Rocking mill
Number of bearings	10	5
Number of crankshafts	2	1
Number of gears	3	0
Number of counterweights	4	1

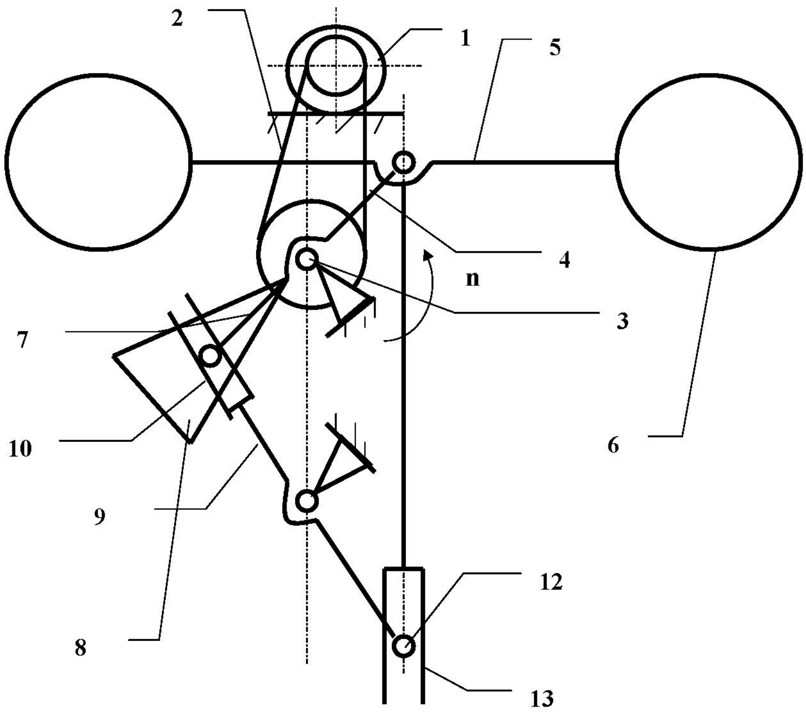


Figure 4 – Scheme of the centrifugal-rocking mill

Technical characteristics of the centrifugal-gyratory mill: productivity 300 kg/hour of ore per hour. Dimensions 1000x 900x800 mm, approximate weight 300 kg, drive power 2.2 kW, shaft speed 500 min^{-1}. The initial pieces are 20-40 mm, the finished product is 40-70 μm (main fraction). The new design of the centrifugal mill is proposed, the specific output of which is 140 kg/kW or 8 kW/ton of product (different types of raw materials were used during the test) [8]. This mill consumes three times less energy than the ball mill. The weight of the proposed mill with a capacity of 10 tons per hour will be at the level of 7-8 tons. The complexity of the structures can be said to be small since the proposed mill has 1 eccentric shaft, 5 bearings, no gears. Weight is reduced by 2 times.

The results of the work are promising for introduction at the enterprises of mining and concentrating industry of Kazakhstan and can be used in mining and processing enterprises of foreign countries.

It should be noted that there are no mills with such operating parameters, according to the open press data. Data on Russia, South Africa, the United States, and Germany were analyzed.

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ТАУ-КЕН ӨНДІРІСІНДЕ ҚОЛДАНЫЛАТЫН ЦЕНТРДЕН ТЕПКІШ ДИІРМЕННІҢ КОНСТРУКЦИЯСЫ

Аннотация. Қазахстан республикасының аумағында орналасқан тау-кен өндірістерін энергияны тиімді қолданатын диірменнің жаңа типті түрімен қамтамасыз ету. Тау-кен өндірісінде қолданылатын қондырғылар арасында диірмен энергияны көп пайдаланатын құралдардың біріне жатады. Сол себепті энергияны үнемді пайдалану өзекті мәселелердің біріне жатады.

Центрленген-гирационды диірмен әртүрлі минералды шикізат көзін уатуға арналған диірмен. Бұл типті диірмендер бұрыннан белгілі және жұмыс істеу барысында жақсы нәтижелер көрсетті. Диірменнің негізгі ерекшелігі электрқуатын тиімді пайдалану болып саналады.

Жазылған жұмыста кулисті механизм негізі болатын центрленген-гирационды диірменнің конструкциясы зерттелген. Бұл диірменнің анық біраз артықшылықтары бар: конструкцияның оңайлатуы, жоғары динамикалық тұрақтылығы, энергия көзін екі есе аз пайдалануы және т.б.

Ең алғаш рет тәжірибелерді «Пайдалы казбаларды байыту Ғылыми-зерттеу институтының» полигонында жүргізілген. Ол Қазақстан Республикасының минералды ресурстарын өңдейтін ұлттық центріне енеді. Диірменнің жұмыс істеу принципі зерттеліп, цилиндрлі ұнтақтағыш камералардың параллельді жазықтық арқылы қозғалыс жасап, камералардың сыртқы диаметрі бойынша кривошиптің ұзындығына сәйкес қозғалады. Центрден тепкіш күштің мәні, салмақсыз динамикалық күштер мен моменттер, сонымен қатар күштік анализ жасалған.

Нәтижелері. Ұсынылып отырған диірменді зерттеу нәтижесінде өнімділіктің үлестік көрсеткішібір тонна өнімге 140 кг/кВт немесе 8 КВт құрайды. Осы көрсеткіштің арқасында зерттеліп отырған диірмен шарлы диірменнен 2 есе артық. Бұл сұлбада механизмдердің теориялық теңдесуі алынған. Елеулі конструктивті жетістіктер бар: бір кривошипті білік, тісті дөңгелектерді қолдануды талап етпейді, артық байланыс жоқ. Соған орай конструкциясының жеңілдеуін байқаймыз. Сонымен қатар, жөндеу жұмыстарының жоғарылағанын байқауға болады.

Ғылыми өзектілігі: центрленген-гирационды диірменнің конструкциясын зерттеп, диірменде өтетін процестерді, яғни ұнтақтау, энергосыйымдылықты, металлсыйымдылықты және диірменнің өнімділігін оңтайлы процестер қатарына енгізу.

Практикалық маңыздылығын. Экспериментaлды және есептеу, сонымен қатар рационалды конструктивті және технологиялық параметрлер негізінде, диірменнің металсыйымдылық көрсеткіші жоғары емес екендігі сипатталып, диірменнің өзқұндылығының арзан болуын айтуға болады, мысалы, шарлы диірменмен салыстырғанда 3 есеге, казіргі таңда қолданылып жатқан центрленген диірмендермен салыстырғанда 1,5 есеге төмен. Сонымен қатар диірменді жөндеуге жарамдылық жұмыстары қиындықсыз жүргізіледі. Ең негізгі көрсеткіші болып – бұл энергияны ұтымды пайдалану көрсеткіші басты рөл атқарады.

Түйін сөздер: центрден тепкіш-гирационды диірмен, ұсақтау, минералды шикізат, металсыйымдылық, энергосыйымдылық, конструкция, өнімділік,уату, кривошип.

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КОНСТРУКЦИЯ ЦЕНТРОБЕЖНО-ГИРАЦИОННОЙ МЕЛЬНИЦЫ ГОРНОРУДНОГО ПРОИЗВОДСТВА

Аннотация. Обеспечить горнорудные предприятия Казахстана новым типом мельницы, имеющей пониженное потребление электроэнергии. Горнорудные мельницы являются основным потребителем электроэнергии в горнодобывающем секторе, в связи с этим задача понижения энергии очень актуальна. Центробежно-гирационные мельницы предназначены для перемола различного минерального сырья. Мельницы подобного типа известны уже достаточно давно и показали неплохие результаты в работе, одним из основных достоинств этих мельниц является пониженное потребление электроэнергии. При практических испытаниях данной схемы основным ее недостатком было выявлено высокая вероятность движения ведомого кривошипа по незапланированному (не штатному) закону движения, что приводит к поломке механизма. Даже малая неточность изготовления механизма, люфт могут привести к отставанию ведомого кривошипа от ведущего, особенно в зоне близкой к крайнему положению.

В данной работе исследуется конструкция центробежно-гирационной мельницы на базе кулисного механизма. Мельница имеет ряд преимуществ перед аналогами: упрощение конструкции, высокая динамическая устойчивость, затраты энергии уменьшены в 2 раза и т.д.

Впервые практические испытания мельниц проводились на полигоне Научно-исследовательского института обогащения полезных ископаемых Национального центра переработки минеральных ресурсов Республики Казахстан. Исследован принцип работы мельницы, который заключается в плоско-параллельном перемещении цилиндрических помольных камер – труб в плоскости перпендикулярной их оси, при котором каждая точка помольной камеры движется по окружности с радиусом равным длине кривошипа r механизма мельницы [5]. Рассчитаны центробежная сила противовесов, неуравновешенная динамические сила и моменты, проведен силовой анализ.

Результаты: Из показателей исследования видно, что предлагаемые мельницы имеют показатель удельной производительности равный 140 кг/кВт или 8 квт на тонну продукции. По этому показателю предлагаемые мельницы превосходят шаровые мельницы в 2 раза [3]. В этой схеме получена теоретическая уравновешенность механизма. Имеются существенные конструктивные достижения: имеется один кривошипный вал, нет избыточной связи, не требуется применения зубчатых колес, что значительно упростило конструкцию. Мельница имеет высокую ремонтопригодность.

Научная новизна. Новизна полученных результатов заключается в создании конструкций центробежно-гирационной мельницы, при которых обеспечивается оптимальный процесс помола, энергоемкость, металлоемкость и производительность мельницы.

Практическая значимость. На основе расчетов и экспериментальных данных, а также в определении её рациональных конструктивных и технологических параметров. Выявлено, что в процессе опытно-промышленного периода мельницы на полигоне Государственного научно-производственного объединения промышленной экологии «Казмеханобр» (Алматы), входящего в состав Национального центра по комплексной переработке минерального сырья Республики Казахстан, что мельница отличается невысоким уровнем металлоемкости, имеет невысокий уровень сложности конструкции, тем самым уменьшается стоимость мельницы по сравнению с шаровыми примерно в 3 раза, по сравнению с существующими центробежными мельницами в 1,5 раза. Испытания мельниц показали их экономичность в потреблении энергии, что является самым главным показателем.

Ключевые слова: центробежно-гирационная мельница, измельчение, минеральное сырье, металлоемкость, энергоемкость, конструкция, производительность, помол, кривошип.