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PRECONDITIONS FOR THE DEVELOPMENT OF A NEW MILL DESIGN WITH A V-SHAPED CHAMBER

Abstract: *The grinding process plays a crucial role in various industries, including mining, cement, chemical, and food production. Despite technological advancements, existing milling technologies often face challenges related to energy consumption, component wear, and process control complexity. This study explores innovative approaches to improve mill designs, focusing on vibratory and ball mills with novel structural enhancements.*

A patent-based review was conducted to analyze different technical solutions aimed at optimizing grinding efficiency. A key innovation discussed is the introduction of an inclined-angle grinding chamber, which facilitates complex motion of grinding bodies, increasing impact directions on material particles. Additionally, vibratory mills with independent unbalanced drives were examined for their ability to enhance grinding chamber oscillations and increase productivity. However, these designs do not ensure counter-motion of grinding bodies, which is critical for maximizing impact energy.

To address this gap, a new mill design is proposed, featuring a V-shaped grinding chamber combined with a vibration drive to induce counter-collision of grinding balls. This configuration significantly enhances impact energy and grinding efficiency. The proposed solution integrates all effective grinding principles, offering a novel approach to achieving superior material processing performance. Further experimental validation is recommended to confirm its advantages over existing designs.

Key words: *mill, grinding process, grinding balls, patent analysis, grinding efficiency.*

Introduction

The grinding process is a key stage in many industries, such as mining, cement, chemical, and food production [1]. The efficiency of milling directly impacts productivity, cost-effectiveness, and the quality of the final product. However, despite technological advancements, existing mill designs often fail to deliver maximum efficiency due to limitations in energy consumption, wear of components, and complexity in process control. Therefore, the improvement of mill designs has become an important area of research and engineering development. Enhancing milling technologies opens up opportunities for reducing costs, increasing productivity, and achieving optimal grinding characteristics, which is crucial for most industries [2].

Materials and methods

To study the practical approaches and directions for improving the designs of mills (grinders) with grinding bodies (balls), various technical solutions of ball and vibratory mills (grinders) were analyzed based on patent analysis and review.

Figure 1 presents one of the options for improving ball mills. The distinctive feature of this design is the introduction of an additional angular parameter between the longitudinal axis of the grinding chamber and the horizontal plane [3].

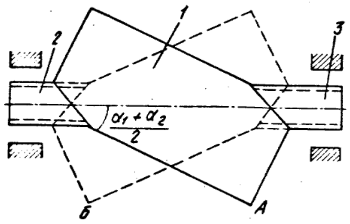

Figure 1 – Ball mill with an inclined-angle chamber

1 – chamber; 2 – shaft; 3 – base

In this design, due to the ability of grinding balls and material particles to move in the longitudinal direction, a complex motion of the load (i.e., grinding balls and material particles) is ensured. Compared to a classical ball mill, this ball mill with an inclined-angle chamber allows for additional longitudinal movement of the load. As a result, the number of impact directions on the material particles by the grinding balls increases.

This mill design ensures a complex rotary motion of the working body. Due to this, the grinding balls perform a longitudinal-transverse movement without using a vibratory drive. The effect of breaking down the coarse material particles is impact-abrasion [4].

Figure 2 shows a structural diagram and an A-A cross-section of a mill (grinder) with an inclined-angle grinding chamber viewed from the side. The grinding chamber (1) and the vibrator (2) are mounted on the frame via springs (4). The unbalanced vibrator (2) is set into rotational motion by a motor (5) through a coupling (6). The grinding chamber (1), installed at an inclined angle with a slotted lower partition (7), is filled with grinding balls (8) up to 70-80% of its total volume. Inside the grinding chamber (1), a ribbed scraper (9) in the form of a rectangular blade is installed.

The scraper (9) is mounted on the upper cover (14) of the chamber and the partition (7) and can rotate around the central axis (10) via bearings formed by a hub (11) and trunnions (12) of the support shaft (13). During operation, the material loaded into the chamber and the grinding balls are in a vibratory-circulatory motion. This promotes mixing of the grinding balls and ensures material grinding (crushing). The crushed material particles exit through the slots in the partition (7).

When processing wet or sticky materials, adhering material lumps are scraped off the chamber walls by the scraper, which rotates slowly around axis (10) under load pressure. This increases the efficiency of processing sticky materials and reduces costs associated with the pre-drying of wet materials [5].

The unique feature of this mill (grinder) compared to other designs is the inclined shape of the grinding chamber, which increases the speed of material passage through the mill (grinder) [5].

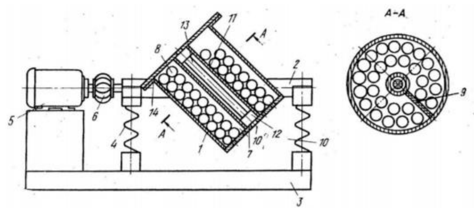

Figure 2 – Vibratory mill with an inclined grinding chamber

In this design, the vibratory-rotary motion of the grinding balls is ensured. The vibratory motion is generated by the vibratory drive, while the rotary motion is facilitated by the scraper. The fragmentation (destruction) effect on the material particles being ground (crushed) is impact-abrasion. The unidirectional movement of the grinding balls is ensured.

The next technical solution is a vibratory mill consisting of a housing (1), which includes a grinding chamber (2) with grinding balls (3), connected to a stationary base (5) through elastic elements (4). This design features two independent unbalanced vibratory drives (Figure 3a).

Each unbalanced vibratory drive is designed as a driven shaft with an individual rotational drive, allowing for independent variation of angular velocity and rotation direction of the drive shaft and unbalanced masses (6). The grinding chamber includes a filling opening (7) for loading the material to be ground (crushed) and a discharge opening (8) for extracting the ground (crushed) product [6, 7].

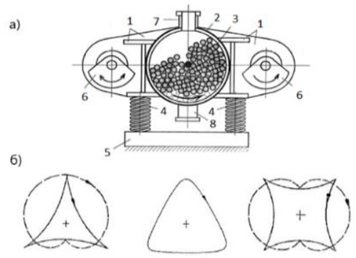

Figure 3 – a) Vibratory mill with two independent unbalanced drives;
b) Trajectories of the biharmonic oscillations of the grinding chamber

The vibratory mill increases productivity by applying two different rotational vibratory effects to the grinding chamber. This solution ensures operation with large amplitudes and frequencies without exceeding the reasonable limit values of mechanical acceleration [4].

By selecting different relationships between angular velocity, centrifugal excitation forces, and the rotation directions of the drive shafts, various vibration trajectories can be obtained. The transformation of non-uniform fields of biharmonic oscillations in the grinding chamber (Figure 3b) enhances the productivity of the vibratory mill [6].

By achieving different oscillation trajectories of the grinding chamber, the load (grinding balls and material particles) exhibits complex motion. This increases the abrasion effect on the material being ground. However, due to the limited increase in the velocity of the grinding balls, the impact effect is relatively low. Additionally, since the grinding chamber does not rotate, the movement of the material is restricted, and counter-motion between the grinding balls and the material is not ensured in this design.

The next design, which increases the intensity of the grinding ball movement, is the vibratory-rotary ball mill developed by Tambov State Technical University for fine grinding (Figure 4). To implement a continuous grinding process, the vibratory-rotary mill is designed with a special loading unit that ensures continuous filling of the grinding chamber with the grinding material.

The vibratory-rotary mill consists of a cylindrical drum (5), which rotates via a motor (1) using a special coupling (2). As the drum rotates, the balls roll and, due to friction forces, rise to a certain height before falling. This results in the grinding (crushing) of material particles between the balls and the drum wall.

The grinding drum is mounted on a movable base (9) and supported by bearing supports (3) and (6). The movable base (9) receives force from a planar vibrator (11) with two unbalanced shafts, connected via springs (10). The drum (5) is divided into grinding chambers by vertical perforated partitions. Each chamber contains grinding balls of different sizes.

An external hatch is provided to ensure the optimal filling level of grinding balls (in this case, 0.8). The raw material is loaded into the chamber through the inlet hopper (7). The material is fed into the mill through an inlet opening (8) located in the end cap above the drum axis. Additionally, the drum includes a perforated section (4) for discharging the final product [8].

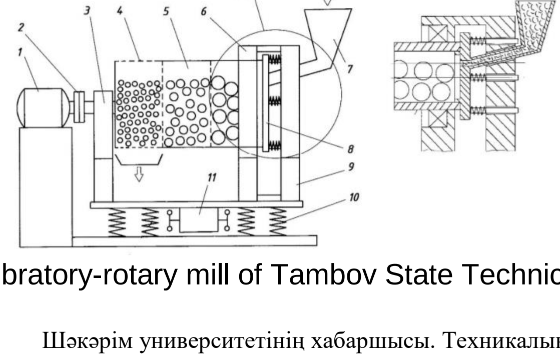

Figure 4 – Vibratory-rotary mill of Tambov State Technical University

In the vibratory-rotary mill developed by Tambov State Technical University, the empty spaces within the grinding chamber are significantly reduced. This is achieved through a more uniform distribution of the material being ground (crushed) throughout the entire drum volume, ensuring more efficient utilization of the working chamber. However, the complex design of the loading unit does not provide high sealing efficiency during grinding (crushing).

As a result, this mill (grinder) is not suitable for wet grinding (crushing), grinding (crushing) in a gaseous medium, or processing explosive materials.

Compared to the previously mentioned designs, this mill (grinder) ensures that the working body performs both vibratory and rotary motions simultaneously. This allows for a complex movement of the grinding balls and material. Additionally, the material particles are subjected to impact-abrasion effects. However, counter-motion between the grinding balls and the material is not ensured in this design.

An improved version of these designs is shown in Figure 5 [9].

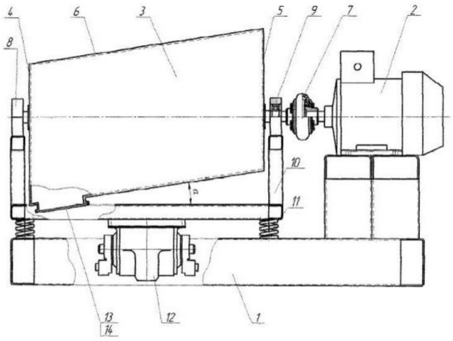

Figure 5 – Vibratory-Rotary Ball Mill with an Inclined Chamber

The mill (grinder) consists of a fixed frame with a drive (2), which is installed on an inclined cylindrical grinding chamber (3). The grinding chamber has end surfaces (4, 5) and a side cylindrical surface (6). The drive (2) rotates the grinding chamber along its transverse axis through a flexible coupling (7).

The grinding chamber (3), which has an inclined cylindrical shape, is mounted on bearing supports (8, 9) as part of a movable frame (10). This movable frame is connected to the fixed frame (1) through vibration isolators (springs) (11). The inclined cylinder's end surfaces (4, 5) are perpendicular to the chamber's rotation axis, while the side cylindrical surface (6) is positioned at an angle to the horizontal plane of the movable frame (10). A vibratory drive (12) is installed on the lower part of the movable frame (10), providing oscillatory displacement to the rotating chamber.

At the bottom of the chamber's cylindrical surface, an inlet-outlet hatch (13) with a removable grate (14) is placed for discharging the ground material [9].

In this design, the moving grinding balls simultaneously undergo translational, rotational, and oscillatory movements in all three planes, creating complex trajectories. As a result, grinding efficiency increases, which is reflected in the improved grinding fineness and a higher specific surface area of the material [10].

A key drawback of this mill is that at high rotation speeds, the longitudinal displacement speed of the material decreases. Consequently, the dynamic component of the grinding process—characterized by impact and abrasion forces along the longitudinal direction—reduces, leading to a lower overall grinding efficiency.

By comparing this mill (grinder) with previously reviewed designs and effective grinding process organization methods, it was determined that this design incorporates all the major advantages except for the counter-motion of grinding balls [4].

Results and discussion

As in the previous section, a comparative analysis was conducted for each fine grinding mill (grinder) considered during the patent review. The results of this analysis are presented in Table 1, which evaluates the designs based on effective grinding (crushing) process organization methods.

Table 1 – The results of comparative analysis of different mill designs

№	Mill type	A set of effective methods for organizing the grinding (crushing) process					
		Method 1	Method 2	Method 3	Method 4	Method 5	Method 6
		Rotary-vibratory movement of working bodies	Mechanical energy transfer	Use of grinding bodies (balls)	Applying a shock-abrasive effect to the grinding material	Counter-movement of grinding bodies (balls) and material	Longitudinal-horizontal movement of grinding bodies (balls)
1	Ball mill with tilting chamber (USSR certificate No. 1827288)	–	+	+	+	–	+
2	Vibrating mill with inclined chamber (USSR patent No. 1243818)	–	+	+	+	–	+
3	Vibrating mill with two independent unbalanced drives (RF patent No. 2501608)	–	+	+	+	–	–
4	TSTU vibrating-rotary mill (RF patent No. 2147931)	+	+	+	+	–	+
5	Vibro-rotary ball mill with a tilting chamber (RF patent No. 105199)	+	+	+	+	–	+

From the Table 1, the first and second mill (grinder) designs correspond to the first, third, fourth, and sixth effective methods of organizing the grinding (crushing) process. The third mill (grinder) design corresponds to the second, third, and fourth methods. Meanwhile, the fourth and fifth mill (grinder) designs comply with the first, second, third, fourth, and sixth methods of organizing the grinding (crushing) process.

However, none of the above-mentioned mill (grinder) designs implement the fifth method which is the counter-motion of grinding balls and material particles.

Based on the results of the conducted analysis, it is concluded that the improvement of the fine grinding (crushing) process should be based on adhering to the previously mentioned conditions for organizing the grinding (crushing) process (methods № 1, 2, 3, 4, and 6) while also ensuring the counter-collision of grinding balls (method № 5).

To implement this principle, a new mill (grinder) design must be developed. As a prototype for the new design, the vibratory-rotary ball mill with an inclined chamber [9] is selected.

The analysis of the existing mill (grinder) designs has shown that a promising principle for improving mills (grinders) is to ensure the counter-motion of grinding balls. The schematic representation of this principle is shown in Figure 6.

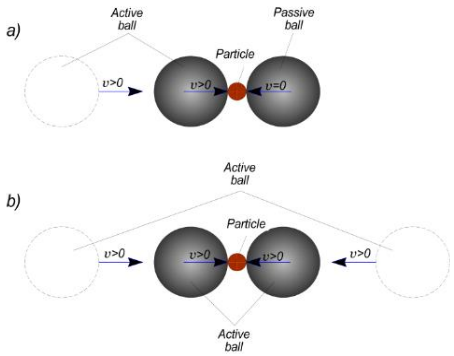

Figure 6 – The principle of grinding process in the proposed design of mill

To implement the proposed principle and verify its effectiveness, a mill design was developed, consisting of a V-shaped grinding chamber, grinding balls, an electric motor for rotating the chamber, and a vibration drive (Figure 7).

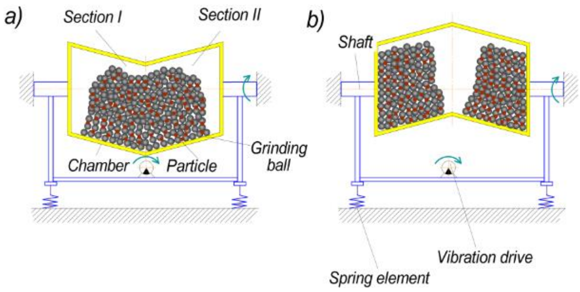

Figure 7 – Schemes of the mill (grinder) design for implementing the new grinding (crushing) principle

a) The position of the chamber at the moment of the counter-collision of grinding balls;
b) The position of the chamber before the counter-collision of grinding balls.

The V-shaped design of the chamber allows for the distribution of grinding balls into two sections (1st section and 2nd section) in the grinding chamber (Figure 7). According to Figure 7a, with the chamber's position, the inclination angle of the section relative to the horizontal axis ensures longitudinal displacement (along the casing). This leads to the counter-collision of the grinding balls and allows for a two-sided impact on the particle. In the case of the chamber's position shown in Figure 7b, the grinding balls roll toward the side wall of the chamber during longitudinal displacement. In this case, a one-sided impact on the coarse particle occurs when colliding with the side wall. To increase the counter-movement speed of the grinding balls, the mill (grinder) design (Figure 7) includes a vibration drive that provides a progressive-reciprocal motion of the chamber in the vertical direction. The increased counter-movement speed of the grinding balls is achieved by projecting the vertical speed of the ball's oscillation onto the inclined line of the ball's movement [11].

Conclusion

Thus, based on the results of analysis of mill designs, the following conclusions can be drawn which are:

1. It has been established that in the classic designs of ball, bead, and vibration mills, the following effective grinding methods are not implemented: combined rotational-vibrational movements of the working bodies, counter-motion of grinding bodies and material, and longitudinal-transverse movement of grinding bodies.

2. It has been established that in the designs of ball and vibration mills, as per patent analysis, all the main methods of effective grinding are implemented, except for the method of counter-motion of grinding bodies and material.

3. A promising direction for improving ball mills is the organization of the movement of grinding balls not in the transverse direction, but in the longitudinal direction, as the intensification of radial movement of grinding bodies is limited by the so-called critical rotational speed of the drum, at which the grinding efficiency sharply decreases.

4. An idea for a grinding principle has been proposed, according to which the increase in grinding efficiency of material particles by grinding balls lies in ensuring the increase of the total impact velocity, and thus the total grinding energy, through the organization of bidirectional (counter) impact of grinding balls on the material particle according to the "active ball - active ball" scheme.

5. A fundamental design solution for a new grinder has been proposed, which, first, implements all the aforementioned methods for ensuring an effective grinding process, and second, differs from existing grinders by implementing the proposed grinding principle, i.e., ensuring bidirectional (counter) impact of grinding balls on the material particle, which should further enhance the grinding efficiency.

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V-ТӘРІЗДІ КАМЕРАСЫ БАР ЖАҢА ДИІРМЕН ҚҰРЫЛЫМЫН ӘЗІРЛЕУДІҢ АЛҒЫШАРТТАРЫ

Ұнтақтау процесі тау-кен, химия және азық-түлік өндірісі сияқты түрлі салаларда маңызды рөл атқарады. Технологиялық жетістіктерге қарамастан, қолданыстағы ұнтақтау технологиялары көбінесе энергия тұтыну, компоненттердің тозуы және процесті басқарудың күрделілігі сияқты қиындықтарға тап болады. Бұл зерттеу диірмендердің құрылымдық жетілдірулеріне бағытталған инновациялық тәсілдерді қарастырады, атап айтқанда, вибрациялық және шарлы диірмендерді талдайды.

Патенттік шолу арқылы ұнтақтау тиімділігін арттыруға бағытталған әртүрлі техникалық шешімдер талданды. Негізгі инновациялардың бірі – ұнтақтау камерасын көлбеу бұрышпен орналастыру, бұл ұнтақтау денелерінің күрделі қозғалысын қамтамасыз етіп, материал бөлшектеріне әсер ететін бағыттардың санын арттырады. Сонымен қатар, тәуелсіз теңгерілмеген жетектері бар вибрациялық диірмендер зерттеліп, олардың ұнтақтау камерасының тербелісін күшейту және өнімділікті арттыру қабілеті анықталды. Алайда, бұл құрылымдар ұнтақтау денелерінің қарсы қозғалысын қамтамасыз етпейді, ал бұл соққы энергиясын барынша арттыру үшін өте маңызды.

Осы олқылықтың орнын толтыру үшін V-тәрізді ұнтақтау камерасы мен шарлардың қарама-қарсы соқтығысуын тудыратын вибрациялық жетек элементі бар жаңа диірмен дизайны ұсынылды. Бұл конфигурация соққы энергиясын және ұнтақтау тиімділігін айтарлықтай арттырады. Ұсынылған шешім барлық тиімді ұнтақтау қағидаттарын біріктіріп, материалды өңдеудің жоғары өнімділігіне жетудің жаңа тәсілін ұсынады. Оның қолданыстағы конструкциялардан артықшылығын растау үшін қосымша эксперименттік зерттеулер жүргізу ұсынылады.

Түйін сөздер: *диірмен, ұнтақтау процесі, ұнтақтау шарлары, патенттік талдау, ұнтақтау тиімділігі.*

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ПРЕДПОСЫЛКИ ДЛЯ РАЗРАБОТКИ НОВОЙ КОНСТРУКЦИИ МЕЛЬНИЦЫ С V-ОБРАЗНОЙ КАМЕРОЙ

Процесс измельчения играет важную роль в различных отраслях, включая горнодобывающую, химическую и пищевую промышленность. Несмотря на технологические достижения, существующие технологии помола часто сталкиваются с проблемами, связанными с энергопотреблением, износом компонентов и сложностью управления процессом. В данном исследовании рассматриваются инновационные подходы к совершенствованию конструкции мельниц, в частности вибрационных и шаровых мельниц с новыми конструктивными улучшениями.

Был проведён патентный обзор для анализа различных технических решений, направленных на оптимизацию эффективности измельчения. Одним из ключевых нововведений является введение помольной камеры с наклонным углом, что способствует сложному движению измельчающих тел и увеличению направлений удара по частицам материала. Кроме того, исследованы вибрационные мельницы с независимыми несбалансированными приводами, которые способны усиливать колебания помольной камеры и повышать производительность. Однако данные конструкции не обеспечивают встречного движения измельчающих тел, что критически важно для максимального увеличения энергии удара.

Для устранения этого недостатка предложена новая конструкция мельницы, включающая V-образную помольную камеру, совмещённую с вибрационным приводом, создающим встречные столкновения шаров. Такая конфигурация значительно повышает энергию удара и эффективность измельчения. Предложенное решение объединяет все эффективные принципы измельчения, представляя собой новый подход к достижению высокой производительности обработки материалов. Рекомендуется дополнительная экспериментальная проверка для подтверждения его преимуществ перед существующими конструкциями.

Ключевые слова: *мельница, процесс измельчения, измельчающие шары, патентный анализ, эффективность измельчения.*

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ИНСТРУМЕНТОВ КРИМИНАЛИСТИКИ: ENCASE И FTK IMAGER

Аннотация: *Дисковая форензика является важной областью информационной безопасности, направленной на исследование цифровых носителей с целью выявления, восстановления и анализа данных, имеющих значение в контексте расследований. В данной работе проводится исследование функциональности и производительности современных инструментов для анализа дисковой форензики. Основной акцент сделан на сравнении возможностей таких программ, как EnCase и FTK Imager, применяемых в данной сфере.*

В процессе исследования выполнен обзор существующих методов и технологий, лежащих в основе работы форензических инструментов, включая поиск удалённых файлов, восстановление файловых систем, анализ метаданных и выявление артефактов, указывающих на следы активности пользователей. Помимо функциональных возможностей, проводится анализ производительности программного обеспечения, включая скорость обработки данных, объем поддерживаемых форматов файлов и эффективность работы с большими объёмами информации.

Особое внимание уделено критериям оценки качества инструментов, таких как точность восстановления данных, пользовательский интерфейс и поддержка автоматизации задач.

Результаты исследования могут быть полезны для профессионалов в области кибербезопасности, судебной экспертизы и ИТ-администрирования, а также для студентов и исследователей, изучающих цифровую криминалистику. Работа направлена на расширение понимания возможностей и ограничений современных инструментов для анализа дисков, что способствует выбору оптимальных решений для конкретных задач.

Ключевые слова: *дисковая форензика, анализ данных, инструменты для криминалистики, восстановление файлов, цифровая криминалистика, информационная безопасность.*

Введение

В эпоху цифровых технологий и массовой цифровизации возникает необходимость защиты информации от кибератак, утечек данных и несанкционированного доступа. Сложность и количество киберпреступлений с каждым годом увеличиваются, заставляя специалистов искать новые методы и инструменты для расследования и предотвращения инцидентов. Важнейшим направлением цифровой криминалистики является дисковая форензика – процесс анализа цифровых носителей с целью восстановления и извлечения данных, имеющих значение для расследования преступлений.

Согласно отчету Herbert Smith Freehills, увеличение объема данных и множества источников требует тщательной подготовки и правильного выбора данных для сбора и анализа, с целью обеспечить успешное расследование. Эти слова подчёркивают важность развития новых подходов и технологий в области цифровой криминалистики.

В корпоративной среде утечки данных наносят компаниям значительные убытки, как финансовые, так и репутационные. Компании полагаются на дисковую форензику, чтобы