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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

IMPROVING THE OPERATIONAL CAPACITY OF GRINDING MILLS USED IN THE MINING INDUSTRY

Speciality: 3313.02 – "Machines, equipment and processes"

Fiel of science: Technical sciences

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The work was performed at the "Industrial Machines" department of the Azerbaijan State University of Oil and Industry.

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GENERAL CHARACTERISTICS OF THE WORK

Relevance and development of the topic. Since the end of the 20th century and the beginning of the 21st century, because of the large-scale implementation of industrialization policy in Azerbaijan, many industrial enterprises with strong potential have been established. At the present stage, to modernize industry and diversify the non-oil industry, it is necessary to involve existing natural and economic resources in the economy, create new production areas, and industrial parks along with traditional industries, and strengthen industrial potential in the regions and create opportunities for industrial development. They are one of the priority areas controlled by the Azerbaijani state. Among these areas, the place and role of the mining industry and related metallurgical sector are of particular importance.

Azerbaijan International Mining Company Limited (AIMCL), which has been developing the Gadabay gold and copper deposits since 2009, is one such company and is currently exploring, extracting, and processing the Gadabay field. The need for high technologies applied in the enterprise and the equipment used in their implementation, creates as well as the application of recovery technologies in technical means after a certain period, as well as the need to update them, as well as various improvements. It is important to note that the frequency of failures in the grinding mills used in the technological chain of the enterprise and the amount of costs associated with their elimination differ significantly compared to others. For this reason, increasing the operational performance and resources of grinding mills, reducing the cost of the processing process, and increasing economic efficiency are among the current problems of the mining industry.

Scientific research in this direction is carried out by scientists and researchers working in near and far abroad, including Andreev S.E., Berrta D., Egorov A.F., Kozin V.Z., Sofiyev A.V., Bond F., Lynch A.D., Horst V.E., Ozgun Levent, King R.P. Luan

K., Nayper-Mann T., Weissberg L.A., Pauls M., Radjimani P.K. Herbest J.A. et al. conducted research of great theoretical and practical importance. As a result, high achievements have been made in expanding the technical capabilities of equipment used in the mining industry, improving technological processes, in general, increasing productivity, ensuring industrial and environmental safety.

Goals and objectives of the study. Increase the operational capacity of the grinding mills used at mining industry in the development of gold and copper deposits.

The following issues were raised and resolved in the dissertation:

- Analysis of the current state and development prospects of the mining industry in Azerbaijan;
-analysis of design features and technical capabilities of grinding mills used in the mining industry;
-analysis of the reasons for refusal in grinding mills;
- Development of the composition and method of preparation of steel balls with high resistance to abrasion and impact strength in grinding mills;
-implementation of constructive improvements in increasing production capacity and resources in grinding mills;
- application of simulation program in optimization of mill operation mode;
-determine the dependence of the mill's productivity on technical and technological parameters.

Research methods. The basics of mathematical statistics and probability theory, theories of operation and environmental safety in nonlinear dynamic systems and mining equipment systems were used to solve the goals and objectives of the research.

At the same time, the issues of risk assessment and forecasting have been resolved through the application of computer technology.

The main provisions of the defense.

-Development of a new recipe and technology that allows to increase the physical and mechanical properties of steel balls used in the grinding mills;

-determine the optimal value of the angle of placement of the shell lifter bars;

- Development of methodological bases of the multi-factor grinding process with the application of a simulation program in determining the parameters of the operating mode;

- Mathematical expression that determines the coordinates of their landing point in accordance with the trajectory of the moving steel spheres;

Scientific innovations of the research:

-determine the location anglee of the lifter bars in order to ensure the efficiency of the grinding process;

-development of a mathematical expression that determines the coordinates of the point of descent of the grinding steel balls in accordance with the trajectory of the grinding steel balls;

-development of a new composition, which allows to increase the physical and mechanical properties of grinding steel balls used in the mill;

-ensure the regulation of uneven wearing in the lifters and shell linings;

-dependence on technical and technological parameters with economic performance (productivity) in the grinding process;

- Dependence of the ratio of the distance between the shell lifter bars (A) on its height (B), as well as the wear limit of the grinding steel balls on the physical and mechanical properties of the processed ore.

Theoretical and practical significance of the research. The results of the dissertation work allow to solve the following practical issues:

-implementation of constructive changes in order to reduce the intensity of wear of primers and increase grinding performance on this basis;

-Development of metal-based composite material and their production technology, which allows to increase the abrasion resistance and impact strength of steel balls.

-Application of the use of metal-rubber coating material in order to reduce wear on the lining of the body;

- Implementation of the MillTraj simulation program for the first time, taking into account the characteristics of the fields exploited in Azerbaijan;

- Empirical expressions that can be used to evaluate the productivity of the design of the shell linings, as well as the operational limit of the wear of grinding steel balls.

- Use of automatic grinding steel ball adjustment equipment to the SAG Mill mill in order to keep the volume of the grinding steel ball stable and increase the grinding performance.

Approbation and application. The results of the dissertation were discussed at the following conferences and seminars:

1. Materials of the XX Republican Scientific Conference of Doctoral Students and Young Researchers (Baku, 2016),
2. At the scientific conference of the Institute of Geology and Geophysics of ANAS (Baku, 2016),
3. 41st International Scientific Conference "Theoretical and practical issues of modern science", Eurasian Scientific Association (Moscow, 2018),
4. VI International scientific-practical conference "Modern scientific research of topical issues, achievements and innovations" (Penza, 2019),
5. Scientific seminar of the Department of "Engineering and Computer Graphics" of ADNSU (Baku, 2020).

The main content of the work has been published in 18 authoritative journals.

Name of the organization where the dissertation work is carried out. The dissertation was completed at the Azerbaijan State University of Oil and Industry. The results of the dissertation work were applied by inspection at the enterprise of Azerbaijan

International Mining Company Limited located in Gadabay contact area.

The total volume of the dissertation with a sign, indicating the volume of the structural units of the dissertation separately. The dissertation consists of an introduction, 4 chapters, general results, list of references and appendices.

The dissertation is presented in 143 pages in A4 format, contains 34 figures, 21 tables, 12 graphics, 121 sources of literature and appendices.

MAIN CONTENT OF THE WORK

The introduction given the topicality of the topic, the purpose of the work and the main research issues, scientific innovations, the practical significance of the results, the main achievements of the defense, the state of application in production and the approbation of the dissertation.

The first chapter reflects the current state and development prospects of the mining industry in the Republic of Azerbaijan, the technologies used in the production and processing of precious metals, and given an wider analysis of the design features and capabilities of equipment and technical means used in the mining industry, and a detailed analysis of the reasons for refusal in the grinding mills.

It was determined that AIMCL, one of the first joint ventures in the mining sector of Azerbaijan, has a leading role in the mining and processing industry in the country and is an important factor in the non-oil sector.

At present, 2 SAG Mill and 2 BALL Mill are operated at the enterprise. The economic efficiency of the processing process is determined by the amount of money spent on productivity (M), energy (E), liners (L) and grinding steel balls (G) in the mills.

As a result of the research, it was determined that the ratio of E: L: G in the SAG Mill mill used in AIMCL is as follows: 58:19:23.

As a result of the analysis of the reasons for the refusals in the mills, it was determined that idleness due to the wearing and falling of grinding steel balls is dominant. According to the existing normative documents, the consumption of grinding steel balls for each ton of ground ore is 0.3-0.8 kg/ton for SAG Mill type mill, depending on their properties. For this reason, as the average daily productivity in AIMCL is 1800 tons/day, 1.0-1.2 tons of grinding steel balls are added to SAG mills once a day. On the other hand, one of the factors that seriously affects the cost of the grinding process is the breakup of the inlet, shell and discharge linings.

Based on these indicators, the main directions and objects of research were selected.

The second chapter is devoted to determining the direction, object, and methods of research.

As a direction of the research work, the issue of increasing the operational capacity of the grinding mills used in the processing of ores extracted from the 3 fields currently operating in the AIMCL - Gadabay, Gadir and Ugur was accepted. Ores extracted from these deposits differ in their morphological properties, wide range of physical and mechanical properties. This has led to the revision and correction of several technical and technological measures with the improvement of regime parameters, grinding steel ball consumption, as well as the design of linings in the process of their processing.

SAG Mill mill and grinding steel balls with diameter d = 100-110 mm (in splitting ore by impact) were selected as the object of research. Depending on the load factor of grinding mills, 16-22 tons of grinding steel balls are usually placed inside them.

The samples of test grinding steel balls prepared at “Azneft” PU “Experimental production enterprise for repair and rental of submersibles (using metal molds), Baku Oil Drilling Equipment” CJSC (using metal molds) and “Baku Steel Casting” OJSC (using land molds).

The hardness of grinding steel balls, as well as the assessment of their wear limit and impact strength were initially carried out by visual observation based on GOST 19200-80 recommendations and in accordance with GOST 9013-59, GOST 26433.1-89 and GOST 9454-78.

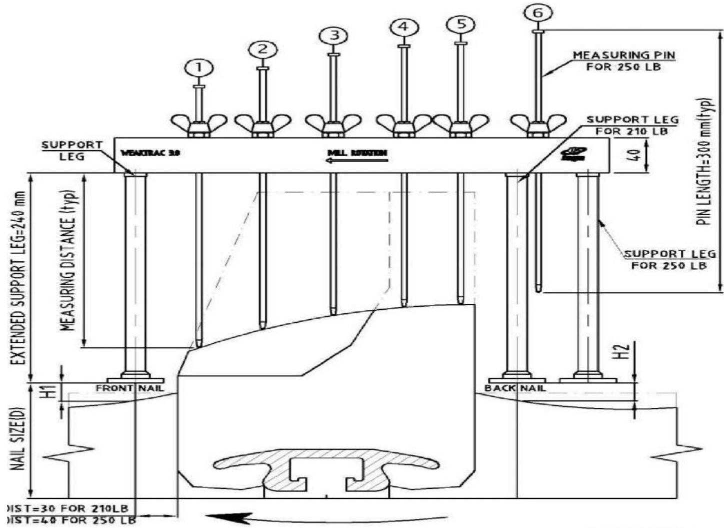


Figure 1. Device for measuring the amount of wear on the linings

Evaluation of changes in diameters with magnifying glass and caliper was used to determine the surface voids and other defects.

The Emco Test -149 hardness tester was used to determine the stiffness. A special measuring device was used to determine the values of wear on the linings (Figure 1.).

Because visual studies of the grinding process pose major challenges, the MillTraj simulation program is used to study the movement of grinding steel balls inside the mill. At the same time, taking into account the multifactorial process of grinding, a planned experimental approach was applied in the experiments in order to study their combined effect.

The third chapter is devoted to the discussion of the results of experimental research. An important factor in assessing the

economic efficiency of the grinding process is the reduction of grinding steel ball consumption and the development of new composite materials and technology for their preparation, optimization of the overall processing mode, the study of the dependence of output on ore hardness and mill drum loading factor The results of studies such as determination of parameters, as well as determination of the angle of placement of shell lifter bars in grinding mills are discussed.
It was found that grinding balls based on the proposed composition and technology differ from their analogues by abrasion resistance and high impact strength (see Graphic 1 and Table 1).

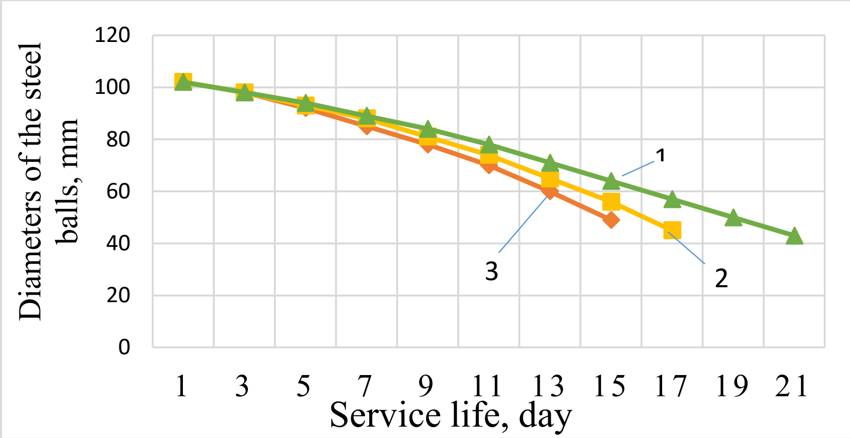
Table 1.

Comparison of physical and mechanical properties of test specimens

Examples	Mechanical properties		Relative abrasive resistance
	KCU, C/sm^2	HRC	
Prototype	70	54	1,23
Offered:			
- in the sand-clayey molds	72	59	1,06
-in metal molds	74	61	1,11

Depending on the type of mills, the hardness of the ore being processed and its functional purpose, their relative load factor has a significant impact on the quality of the grinding process. As a result of the tests, it was determined that the perfect values of the output of the product occur when the grinding steel ball load is 14%.

On this basis, in the later stages of the research, the load factor of the mill drum was adopted at this level.



Graphic 1. Dependence of wearing on grinding balls on the properties of ore: 1-Ugur field; 2-Gadabay field and 3-Gadir field

Table 2.

Mineralogical composition of ore on deposits

Name of the field	Hardness, From the Mohs table	The amount of precious metals in the ore, g/ton		
		Au	Ag	Cu,
Gadir	6-8	4,87	8,96	0,04-1,2
Gadabay	4-6	1,03	8,25	0,25-0,64
Ugur	3-5	1,2	6,3	0,08

Table 2 shows the parameters of precious metals extracted by deposits.

Table 3 provides information on the results of observations on changes in grinding steel balls and energy consumption depending on the degree of hardness in the processing of ores extracted from the Gadabay, Gadir and Ugur fields for 2015-2021.

Table 3.

Variation of steel ball and energy consumption depending on the degree of hardness of ores

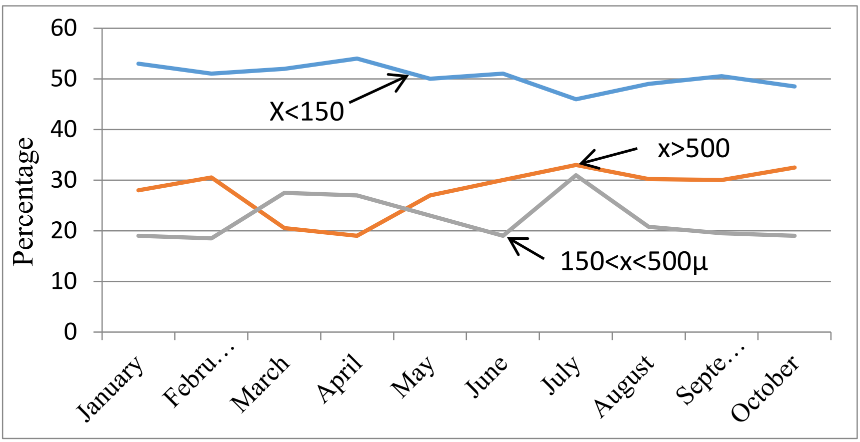
Field	Average hardness from the Mohs table	Productivity, ton/hour	Steel ball consumption, kg/ton	The service life of steel balls, hours	Required energy consumption, kW/hour
Gadir	6,5	66	0,65	390	610-630
Gadabay	5,0	82	0,56	420	570-580
Ugur	3,5	110	0,48	450	490-550

As can be seen from the analysis in Table 3, energy consumption can vary by more than 8-15% and grinding steel ball consumption by more than 24-36% depending on the hardness of the ground ore. At the same time, it was determined that the maximum grinding limit (66 tons/hour) was achieved in the SAG Mill using a maximum of 83-88% of engine power (810 kW) when working with ore from the Qadir field. When the density inside the mill was less than 69%, the percentage of coarse grains in the output increased, and at lower densities the load factor of the mill changed and began to load gravel larger than 40 mm. At the same time, as a result of the reduction of the layer of mud that forms a protective layer on the linings, the direct contact with the linings increased, which had a serious impact on their service life.

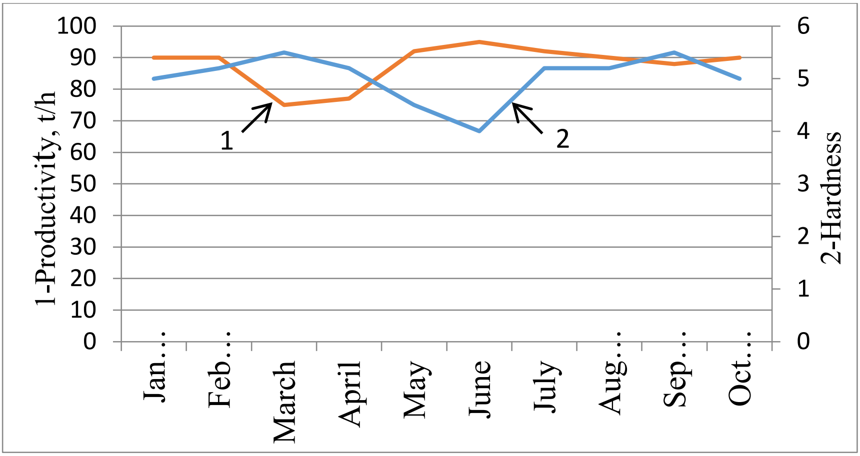
As a result of the tests, it was determined that the yield of ore (ore fineness) is up to 28% for l> 500 microns, up to 21% for grains with an interval of 150 <l <500 microns, an for the finest fraction l <150 microns up to 51% can be adjusted. It has been established that the type of ore that causes problems in the grinding process at the SAG Mill is a derivative of quartzized rhyolites. Thus, when they rotate inside the mill, they move along the ball-shaped grinding steel balls and cause additional loading of the mill. Graphic 2 shows the output indicators (a) and productivity (b) of the ore grinding process by months in the AIMCL.

The results of research on the selection, design and structural dimensions of the lining material installed inside the SAG Mill to assess the impact on the quality and productivity of the processing process are shown in Figure 2.

Based on the analysis of the results of studies on the abrasion of the linings of the body, it was determined that the wearing is intensive in the linings of the first row due to the interaction of large ore masses and grinding steel balls at the entrance.



a)



b)

Graphic 2. Ore grinding process output (a) and productivity (b) index.

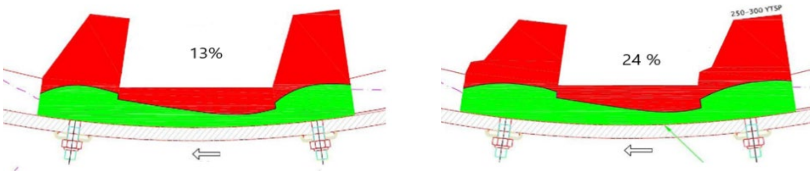
Figure 2. The nature of the wear on the linings

The amount of abrasion in the second row of rubber-metal coatings is less than in the first row. Thus, the ground ore slows down the abrasion process by creating a layer on the lining. The large pieces of ore at the entrance were mostly minced and some were effective for subsequent grinding.

As a result of the analysis of the working surfaces of the linings in the third row, it was determined that the ore masses larger than the discharge plate size of the mill accumulate towards the outlet, and the ground ore is already transferred to the process through the mill. There is a small amount of ground ore left at the outlet, and pieces larger than the outlet size and the grinding steel balls come into contact with the lining, resulting in intensive abrasion.

In order to improve the real situation, there is a need to intensify the sizereduction process at the mill. For this reason, in order to increase the number of strokes of grinding steel balls, increasing the size of the shell lifter bars and the variable speed of the mill drum were used as a technological advantage. 2 forms of shell lifterbars have also been proposed with modified degree sizes (see Figure 3).

It was found that the first of the proposed forms was 18% larger than the previous form, the weight of the eaten part was 13% more and the degree size was 64. The second form was 9% larger than the existing form, weighed 24% more, and had a degree size of 76.



a) b)

Figure 3. Wearing of the shell linings

In general, the results of wear analysis show that the wear limit in the first row of primers is in the range of 55-60%, in the second row of liners in the range of 45-50%, and in the third row in the range of 75-80%.

Studies have shown that one of the factors that significantly affects the quality of the ore processing process in SAG mills is the ratio of the distance between shell lifterbars (A) to the height (B) of the shell lifterbars.

Figure 4 shows a layout describing the ratio of the distance (A) between the shell lifterbar to its height (B).

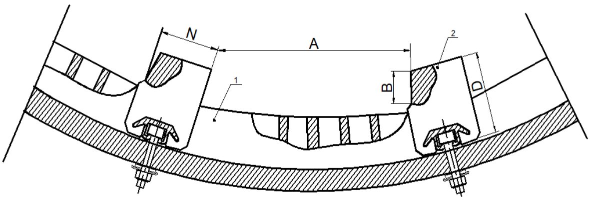


Figure 4. Layout of placement of shell linings in SAG mill

Based on our research, as well as the results of numerous experiments, as well as analyzes in MillTraj simulation programs, in SAG-type mills (diameter D = 5.0 m) the ratio of the distance between the lifting linings (A) to its height (B) (A) / B) gives the basis for the recommendation of the following empirical expression between the design parameters of the rational value for the mill:

$$\frac{A}{B} = (1 - \frac{70-\beta}{100}) \cdot \frac{\pi(D-2b)}{D} \cdot K \qquad (1)$$

Here: K is the correction factor and K = 0.76 for SAG Mill and K = 1.044 for Ball Mill; A- the distance between the shell lifter bars; B- height of the shell lifterbars; D - diameter of the mill drum;

b is the thickness of the lining and β is the percentage of the calculated critical speed.

Graphic 4 showen results of the (4) trend of daily indicators changes during the first six months of 2018 the productivity (1), grinding steel ball consumption (2), drum rotation speed (3) and size distribution in the output product, and which its directly affect the mill's performance with the use of newly designed liners at the SAG Mill.

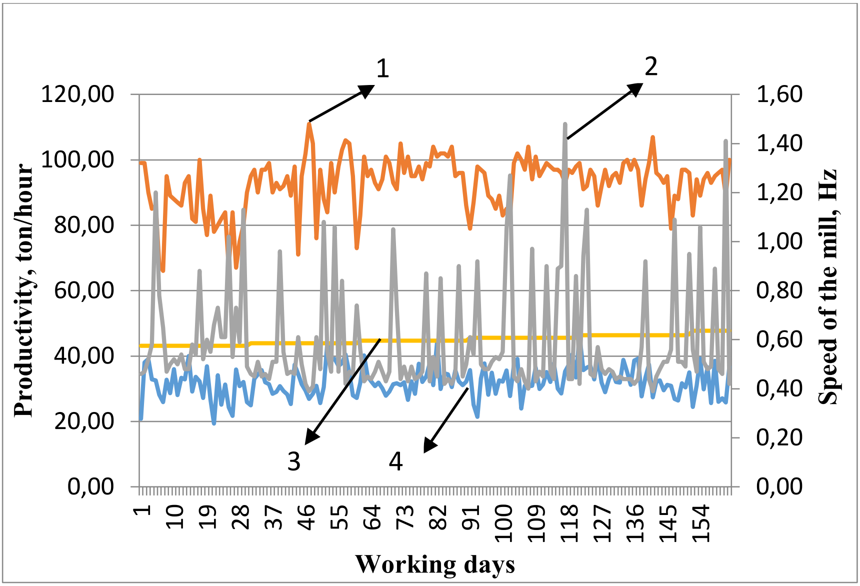
The analysis of the graphs shows that the grinding steel balls has a direct effect on the size of the ore fineness in the output product due to the incorrect compensation of the ball consumption (2).

Thus, the volume of grinding steel balls and ore grinding in the mill manifests itself as a throbbing, as the loading of grinding steel balls in the mill once a day and their average volume during the day reduces by 0.5 kg per ton of ore.

At the same time, one ton of grinding steel ball was urgently added when the percentage of + 500 μm ore in the output increased, as changes in daily working hours and changes in productivity due to the hardness of the ore disturbed the loading balance of the grinding ball in side the mill. In this case, a change in the degree of the size reduction was observed in the output product.

As a result, there is a need to install a system of automatic steel balls loading to the mills, and its provision is urgent.

As can be seen from the graph, after the 112th day of operation, productivity began to decline in part. The reason for this is the reduction in the height of the shell lifter bars and the fact that after some time the mill will not be able to perform enough chopping functions as it rotates the drum (grinding steel balls cannot lift and strike along the trajectory). In order to increase the intensity of the blows, the speed of the mill drum was regulated and the consumption of grinding steel balls was increased. At the same time, due to the reduction in the height of the shell lifter bars, the volume of the grinding steel balls increased due to the decrease in the impacting volume of the grinding steel balls.



Graphic 4. The effect of intermittent ball addition on grinding

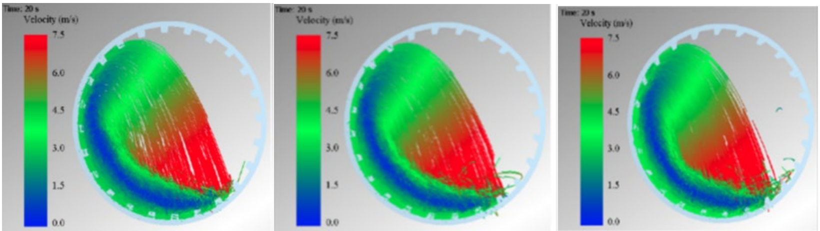
Decreased productivity, increased consumption of grinding steel balls, and increased grinding performance result in the fact that shell body liners end their service life.

As a result of the application and practical tests of the MillTraj simulation program, the following empirical relationship between the wear limit of grinding steel balls and the parameters controlling the process during the processing of ores in the SAG Mill mill was confirmed:

$$Y=k_1\cdot(H+4)\cdot V^a\cdot T^c=(0{,}012\cdot H+0{,}048)\cdot V^{0,2}\cdot T^2 \qquad (2)$$

Here: Y - wear limit of grinding steel balls; k1 is the correction factor; V is the rotational speed of the mill drum; H is the Mohs hardness of the processed ore; T is the service life of grinding steel balls; a, b and c are the copy ratios, respectively.

The results of studies on the effect of determining the placement angle of shell lifter bars in grinding mills on processing are shown in Figure 5.



Location angle 76°, speed 12.6 rpm | Location angle 64°, speed 13.5 rpm | Location angle 55°, speed 14.3 rpm

Figure 5. Grinding process simulation

As can be seen from the analysis of Figure 5, the mill drum speed of 12.6 rpm was determined to maintain the impact trajectory of the shell lifter bars with a positioning angle of 76 degrees in the first stage. After a certain period of time, as a result of abrasion in the linings, the angle of the shell lifter bars increases up to 70 degrees. In this situation, in order to maintain the level of productivity, it is necessary to increase the number of cycles to 13.1 rpm. As a result of continuous research under normal operating conditions, the number of revolutions of the mill drum was increased to 14.3 rpm in order to keep the impact trajectory stable.

It was found that the quality of the processing process depends on the stability of the regime parameters in the mills. For this purpose, the technology of adding 1 ton of grinding steel balls to the drum once a day is incorrect. As a result of the research, it was approved and implemented that the adding of steel balls to the mill should be continuous.

The fourth chapter is devoted to the application of research results and the assessment of their feasibility.

The work done to increase the efficiency of the grinding process in AIMCL was carried out in 3 directions: material selection, application of technological and constructive innovations.
The purpose of the research and the proposals and recommendations arising from the process of implementation of the issues envisaged for its solution have been gradually implemented in the AIMCL.

Stage 1. Improving the efficiency of the grinding process by increasing the hardness, impact viscosity, and abrasion resistance of grinding steel balls used in the mill.

Stage 2. Ensuring the optimality of technological parameters, taking into account the physical and mechanical characteristics of the processed ore.

Stage 3. Development of ways to eliminate them as a result of extensive and in-depth analysis of the causes of wear on the linings.

Table 4 compares the amount of abrasion that occurs in grinding steel balls operated on the basis of the existing and proposed technology. As can be seen from the comparative analysis, the changes in the diameter (abrasion) of grinding steel balls made on the basis of existing and proposed technology differ significantly. Grinding steel balls, which lose $Y \leq 50\%$ each time, are excluded from further testing.

As can be seen from the analysis of the Y change in the grinding steel balls with a diameter of $d = 100$ mm, the value of this change in the Ugur, Gadabay, and Gadir fields after the first 3 days is (2.6-3.8) / (1.5-2, 3), after 5 days (6,2-9,4) / (3,2-5,7), after 10 days (14,4-26,8) / (8,1-14,8), and after 15 days it was (34.6-51.5) / (16.2-25.7).

The comparative analysis shows that although the ore from the Qadir field loses more than 50% of its size on the 15th day of operation when processed using existing grinding balls, the proposed grinding steel balls are able to retain their capacity and continue their resources on the 20th day of operation it only 32.5% of their source used.

Table 4.

Comparison of the amount of abrasion that occurs in the steelballs operated on the basis of epyexisting and proposed technology

Name of the field and the diameter of the used steel balls	Abrasion on steel balls by diameter, %				
	Service life, days				
	3	5	10	15	20
Gadir, d=100 mm	3,8	9,4	26,8	51,5	-
d =125 mm	2,3	5,7	14,8	28,7	40,5
Gadabay, d=100 mm	3,2	7,8	21,6	44,4	56,4
d =125 mm	1,8	4,1	12,8	23,8	37,4
Ugur, d=100 mm	2,6	6,2	14,4	34,6	48,5
d =125 mm	1,5	3,2	8,1	16,2	23,8

The mathematical relationship between the performance of the process and the technological parameters is as follows.

$$M = 20{,}31+0{,}594\cdot X_1 +1{,}214\cdot X_2+0{,}091\cdot X_3- -9{,}582\cdot X_4+0{,}001\cdot X_2\cdot X_3+0{,}002\cdot X_1\cdot X_3- 0{,}021\cdot X_1\cdot X_4 - 0{,}011\cdot X_3\cdot X_4 \quad (3)$$

As can be seen, factor X4 (an indicator of the hardness of the grinding ore) is an important factor in all input parameters and adversely affects the process. The effect of other factors on the grinding process takes place in the following sequence - X2, X1, and X3, respectively.

Table 5.
The relationship between the trajectory of the steel balls and the productivity of the mill

Trajectory (k)	1,0	0,92	0,8	0,56	0,42
Loading (X_1)	22,5	20,0	17,5	25	15
Critical speed (X_2)	73,6	72,05	70,5	68,95	67,4
Angle degree (X_3)	64	70	58	76	52
Hardness (X_4)	3	4	5	6	7
Productivity , MilTraj	107	95	80	70	55
The results of the study	105,4	94,6	79,54	70,57	46,82
Report	103,9	90,56	74,57	70,12	47,38

X2 (speed factor) is more important than the mill load factor (X1) and the degree of angle of the shell lifter bars (X3).

At the end of the study, it was determined that the correct choice of the trajectory of grinding steel balls depends on the loading coefficient and hardness of the ore, the number of cycles of the mill drum, the angle of the lifter bars is affecting the productivity of the grinding process, as well as processing quality, and overall efficiency. The comparative results of the study of the grinding process in real conditions and through the Milltraj simulation program are given in Table 5.

Figure 6 shows the possible trajectories of grinding steel balls. Here, the ideal position of the trajectory of the grinding steel spheres is marked as k = 1.0. K = 0.92-0.95 for Toe zone α = 35-40 degree, respectively, for other positions of the shell lining location angle; k = 0.8-0.88 for α = 22-27 degree; k = 0.56-0.78 for $\alpha \geq 40$ degree and k = 0.42-0.60 for $\alpha \leq 22$ degree.

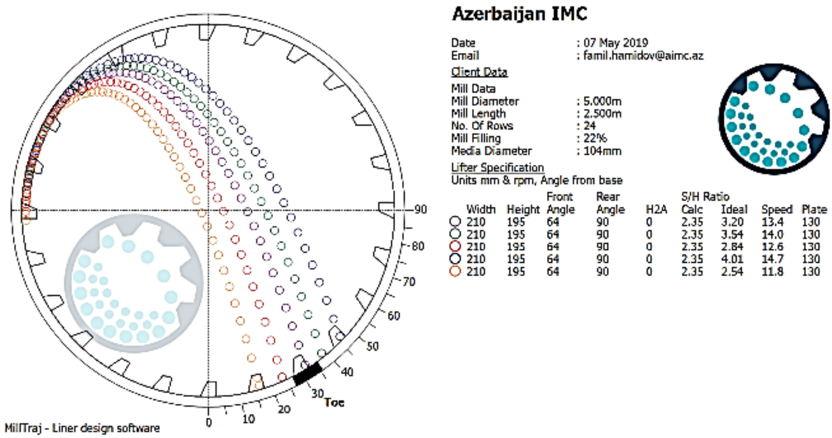


Figure 6. Possible trajectories of steel balls

MAIN RESULTS

1. The performance of the SAG Mill used in the mining industry depends on several factors (15 variable and stable parameters), where the efficiency of the ore grinding process is determined mainly by energy, grinding steel ball consumption, and wear of linings.
2. New formulations and technologies have been developed and applied to develop grinding steel balls that increase the efficiency of the grinding process and demonstrate high abrasion resistance and impact properties. The properties of the grinding steel balls obtained based on the proposed new recipe and technology are superior to the similar properties of the grinding steel balls used in the AIMCL.
3. It was determined that the energy and grinding steel consumption in the mills varies in the range of (8-15)% and (24-36)%, respectively, depending on changes in the

composition and hardness characteristics of ores from the Gadir, Gadabay, and Ugur fields. It is recommended to take this factor into account in determining the technological parameters of the grinding process.

4. Taking into account the dependence of the quality index (degree of grinding) of the product processed in the SAG Mill on the physical-mechanical (strength and hardness) properties of the ore, adjusting the technological parameters of the process (rotational speed and load factor of the mill drum) %, the interval of the size distribution 150 <l <500 μm can be adjusted up to 21% for grains and up to 51% for l <150 μm.
5. Considering the location angle of the shell lifter bars and the design of the linings in the SAG Mills, to make them in accordance with the design parameters (B = 190 and A = 427) using metal-rubber composite material as a coating layer at α = 64-70 degree is appropriate. Thus, it was possible to increase the longevity of the shell lifter bars to 4170-4230 hours, the service life of the entrance and middle row shell linings to 7490 hours, and the resources of the shell linings at the exit to 4170-4230 hours.
6. To increase the efficiency of technical and technological adjustments in the processing process, empirical expressions have been proposed: to assess the ratio of the distance between the shell lifter bars (A) to its height (B), as well as the dependence of grinding steel balls on the physical and mechanical properties of processed ore.
7. Mathematical models of dependencies between mill productivity and technical and technological parameters allow determining the coordinates of their landing point in accordance with the trajectory of grinding steel balls, the relationship between productivity, and the main parameters of the process with high accuracy.
8. Lack of appropriate mechanized or automated means for changing primers makes this process manual. This confirms

the importance of considering the weight limit in the design and manufacture of substrates.

9. It is recommended to use the first of 100, 110-, and 125-mm diameter grinding steel balls used in the grinding process in SAG-type mills.
10. Proper regulation of energy and grinding steel consumption in the grinding of ores from the Gadir, Gadabay, and Ugur fields in the SAG mill ensured productivity at 66, 82, and 110 tons/hour, respectively.

LIST OF PUBLISHED WORKS ON THE SUBJECT OF DISSERTATION

1. Hamidov F.M., Habibov I.A. Analysis of abrasion intensity of parts of mills used in the mining industry of Azerbaijan. Scientific works of “Geotechnological problems of oil and gas and chemistry” Research Institute, Baku: Volume XVI, 2015, P.282-287 (Article)
2. Hamidov F.M. Improving the performance of grinding mills used in the mining industry. Materials of the XX Republican Scientific Conference of Doctoral Students and Young Researchers, Baku, 24-25 May 2016, ASOIU-printing house, Volume 1 C.307-308 (conference materials).
3. Hamidov F.M. Development of new steel material for the production of grinding balls. Caspian Oil and Gas Scientific-Practical Conference, Baku, 2016, P.68-71. (Conference materials).
4. Babanli M.B., Huseynov B.H., Gafarov N.A., Habibov I.A., Aliyev E.A., Hamidov F.M. Method of production of grinding steel balls. Patent Trademark Center of the Republic of Azerbaijan, № 2017 0064. Registration in the State Register 05.12.2017.
5. Hamidov F.M., Chakraborti P.P., Habibov I.A. Results of improvements in SAG mills applied at Gadabay mine. News

of Azerbaijan Higher Technical Schools, Volume 20, №2 (112), 2018, P.7-12 (Article).
6. Habibov I.A., Hamidov F.M., Chakraborty P.P. The results of the upgrades of SAG-type mills used by the Azerbaijan International Mining Company. Izvestia of Ural State Mining University, 2018. №2 (50). C. 102-106. (Article).
7. Hamidov F.M. Modern state and prospects of development of mining industry of Azerbaijan. Proceedings of the XLI International Scientific Conference "Theoretical and practical issues of modern science", Eurasian Scientific Association, №7 (41), 2018, P.28-29. (Conference materials).
8. Habibov I.A., Hamidov F.M. Assessment of the impact of ore from the Gadabay, Gadir, and Ugur fields on the capacity of grinding mills. Scientific works of AzTU, №1, 2019, P.84-87. (Article).
9. Habibov I.A., Hamidov F.M. Optimization of the process of operation of grinding mills used for crushing ore. Collection of articles VI of the International scientific-practical conference MODERN "Scientific research of topical issues, achievements and innovations", 2019. г. Penza, P.48-52 (Article).
10. Hamidov F.M. Determination of optimal values of parameters affecting the ore grinding process in SAG MILLS. Equipment. Technologies. Materials. 2019, №1, P.25-31.
11. Hamidov F.M. Optimization of the working process of drum mills. News of Azerbaijan Higher Technical Schools, Volume 21, №5, 2019, P.71-78 (Article)
12. Hamidov F.M., Habibov I.A. Establishment of the relationship between productivity and technological parameters of the process of grinding ore in ball mills. International Journal of Innovative Technology and Exploring Engineering (IJITEE), volume-9 issue-1, November 2019.
13. Hamidov F.M**.** Determination of design parameters of protective coating in grinding mills. Equipment. Technology. Materials. №2, 2019, P.25-31.

14. Hamidov F.M. Determination of the optimal parameters of the design of shell lifter bars mills type SAG MILL. National Association of Scholars (NAU), 2020, №1, P.14-18
15. Hamidov F.M. Technology for obtaining high mechanical properties of grinding steel balls. Equipment, Technology, Materials. Volu me 03, Issue 01, 2020, P.43-48.
16. Habibov I.A., Hamidov F.M. Determination of optimal design dimensions of shell lifter bars in SAG MILLS. Scientific Works of the Azerbaijan State Maritime Academy, №2, 2020, P.180-186.
17. Hamidov F.M. Determination of the relationship between the wear rate of grinding balls in the sag mill and the parameters that control the process. Equipment Technologies Materials, Volume 5, Issue 1, 2021, P. 26-28.
18. Hamidov F.M., Habibov I.A. Integration of automatic ball adjusting device into the grinding process system of "Azerbaijan International Mining Company Limited". Equipment Technologies Materials, Volume 09, Issue 01, 2022, P. 4-9.

Personal contribution of the applicant in the published scientific works in connection with the research:

Works [2, 3, 7, 10, 13, 14, 15, 17] were performed independently by the author;

In [1, 4, 5, 6, 8, 9, 11, 12, 16, 18], the authors set the problems, performed theoretical and experimental research, and analyzed the results on an equal footing.

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