About transition processes in blasthole drilling at quarries

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Abstract. As a system, the mining enterprise develops under constantly changing conditions of the external and internal environment. These conditions affect the state of the most important drilling subsystem: blasthole drilling technology, safety, performance, power consumption of the boring rigs and roller bits used. The main transition processes as necessary responses of the subsystem to changing conditions were identified as a result of fragmentary data analysis showing decisions taken over the past 15-20 years, which increase drilling activity efficiency and safety of smaller quarries of Russia, which contain a significant amount of material resources. The main transition processes contribute to the growth of drilling performance and consist of changing the following: bit design for specific rocks; drilling method; drilling mode; boring rig design; controlled parameters of drilling process and rock properties redetermination; parameters of maintenance and repair system. Based on the performed analysis, the systematization results of the main factors predetermining the need for transition processes implementation in the "drilling operations" subsystem were obtained and presented. The proposed approach allowed to reveal a holistic picture of the main interacting factors in the "drilling operations" subsystem. Based on the factors systematization presented in the article it is possible to envisage changes of individual factors depending on changes of other factors, not functionally related directly when planning drilling operations.

1 Introduction

At the present stage of operation, mining companies are large holdings and corporations that consume significant resources in the development of mineral deposits. Their operating conditions affect both general mining technology and drilling technology. Considering that drilling operations are associated with significant costs for the acquisition and operation of equipment used, boring tools, then untimely accounting of new drilling conditions for production wells in the development strategy of complex structure deep deposit planning can cause significant damage to the mining enterprise in the nearest and more distant perspective. Thus, changes in external and internal environmental factors necessitate early implementation of technological transition processes and drilling operations arrangement,

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which are the actions made in the innovative decisions' implementation on drilling operations parameters adaptation to the changing conditions of the mining enterprise functioning [1,2]. Widespread variety of drilling equipment, availability of scientifically sound solutions to improve the drilling tools reliability [3,4] and innovations in the field of blasthole drilling information technologies [5-9], research [10-15] in the field of boring rigs fleet completing optimization at quarries to minimize drilling costs - all of it creates a reliable basis for transitioning processes selection to adapt drilling parameters to changing conditions. In such a situation, mining companies are forced to conduct a thorough review of their activities to identify genuinely essential solutions. The greatest difficulty in assessing possible reserves to increase efficiency and reduce risks of hazardous situations for the company is the low awareness level of the different factors impact under specific conditions. Factors significance assessment is often made based on the experience and intuition of individual specialists of mining enterprises. This approach does not consider the systemic factors impact and critical inter-factorial linkages, resulting in either over expenditure or lack of resources and increased risks of production losses.

2 Identification of major transition processes implemented in drilling operations on major quarries of Russia

Based on the data obtained by Institute of mining of the Ural branch of the Russian Academy of Sciences [16-18] and specified in the literature [19-29], the main transition processes carried out in carrying out drilling operations on mining enterprises of Russia were determined. The studies considered measures or actions implemented over the past 10 to 15 years in mining enterprises that achieved planned capacity and faced the need for transition processes implementation in drilling operations. The totality of the diverse identified data on drilling operations transition processes in various mining enterprises has been classified into several main groups (table 1). Table 1 also shows the transition processes implementation results and their impact on related mining processes (explosive rupture, excavation, transportation, primary breaking in a crushing-and-concentrating plant).

As a result of the study, it was determined that the efficiency and safety of drilling operations is mainly determined by transition processes related to obtaining information on the state of the rocks in natural deposit, change in the method and mode of drilling, design of boring rigs and tools, parameters improvement of maintenance and repairs system. As shown by the analysis, these areas have significant reserves for the development of drilling operations and deserve special attention in stabilizing the changing conditions influence of open mining operations. The studies also showed that in order to improve the drilling operations efficiency in mining enterprises, transition processes that disclose internal reserves of boring rigs and tools without significant production capital investment should be used. It was also found that the productivity growth potential of drilling machinery is mainly considered in the assessment of the possible effect from the transition processes implementation in drilling operations. Thus, having information on the need to optimize certain factors affecting the efficiency and/or safety of quarry drilling operations, it is possible to identify a potential list of adaptive transition processes based on table 1. Subsequently, the selected transition processes should be brought to full compliance with the conditions of a particular mining enterprise.

Table 1. Transition processes in drilling operations at mining enterprises of Russia

Group	Transition process	Mining enterprise	Implementation results in enterprises	Objective factors		
				Systemic		Organizational and technical
1	2	3	4	5		6
I	Changing the bit design for specific rocks	Uralasbest JSC Kachkanarsky GOK, Kostomukshsky GOK [16], Polyus PJSC	Increasing bits endurance, reducing drilling tool costs by 35 -40%.	Parameters of blasthole drilling process		Blasthole diameter
						Design parameters of roller bit
						Drilling tools durability
		Kachkanarsky GOK [17, 18]	Increasing boring rig productivity by 2-2.5 times in comparison with rotary BR - 250MN. High quality rock crushing is provided.			Mechanical drilling speed
						Drilling rig performance
						Drilling unit costs
				Influence on related process	Explosive rupture process	Particle size distribution of ruptured rock
						Shape and width of exploded rock
						Explosive application rate
						Mined rock output
		In the conditions of Kostomukshsky GOK [19] In the conditions of quarry of Krasnoyarsk Krai and Khakassia - Gorevsky GOK, Polyus PJSC [20]	The application of foreign roller bits provided durability increase by 2 times compared to bits of domestic production. The cost of foreign roller bits exceeded the cost of domestic bits by 2 times and more.		Process of excavation	Excavator bucket capacity
						Loading cycle duration
						Excavator productivity
						Excavation energy intensity
					Transportation process	Vehicle body space
						Vehicle cargo carrying capacity
						Energy intensity of transportation
						Vehicle productivity
					Primary breaking in a crushing-and-concentrating plan	Crusher parameters (grip angle, throughput, motor power)
II	Changing drilling way	at most of Russia's quarries	As a result of the transition from the cable-churn drilling method to the roller-bit drilling, drilling productivity has been significantly improved and economic costs have been significantly reduced.	Parameters of blasthole drilling process		Rupture mechanism parameters
						Auxiliary operations time
		Mikhailovsky GOK. Selectively on selected sites	A partial shift to the thermal drilling mode provided improved drilling productivity. Thermal drilling method has a limited application scope due to SiO_2 content in the rock massif (must be at least 68 -72%).			Operations' laboriousness
						Mechanical drilling speed
						Rig time usage ratio
						Drilling tool structure
						Drilling process safety
III	Changing the drilling regime	Coal strip mines of SUEK [21-23], quarries of Alrosa PJSC, Polyus PJSC, Mazulsky limestone mine of Rusal-Achinsk JSC, Nefelinovy mine of Rusal JSC,	Reduced engine room floor vibration and machinist workplace vibration, increased replacement performance by 15 percent or more.	Parameters of blasthole drilling process		Mechanical drilling speed
						Drilling rig performance
						Bit durability
			Increase in drilling speed by 30— 40% without roller bits durability reduction.			Oscillation dynamics of drill string and roller bit
IV	Improvement of boring rig design	On the quarries of Russia: Kachkanarsky GOK, Lebedinsky GOK, Mikhailovsky GOK,	As a result of the factory modernization of SBSH-250MNA-32 drilling rigs carried out by Rudgormash JSC over the past 15 years,	Parameters of blasthole drilling process		Mechanical drilling speed
						Shift time
						Working time utilization factor
						Auxiliary operations time
						Hole diameter

Group	Transition process	Mining enterprise	Implementation results in enterprises	Objective factors		
				Systemic		Organizational and technical
1	2	3	4	5		6
		Olympiadinsky GOK, etc. [24-26]	drilling productivity has been increased by 15-20%. The enterprises operate new high-performance frame and platform drilling rigs SBSH 250/270-60 KP, which improved the repair organization and increased reliability of rigs operation.			Mobility of drilling machinery
						Drilling rig performance
			Increasing control over drilling tool flow.			Rig control
V	Control of drilling process and rock properties redetermination	Karelsky Okatysh JSC, Polymetal JSC, Ayhalsky GOK, Polyus PJS, Olenegorsky GOK (Olkon) [27, 28], Razrez "Tugnusky" JSC, SUEK-Kuzbass JSC	Safety increase of drilling operations (creation of remote-controlled rigs to operate on ALROSA quarries at narrow sites with high collapse risk).	Parameters of blasthole drilling process		Accuracy of spacing pattern compliance with project parameters
						Bit durability
						Drilling mode
						Drilling rig guidance accuracy at the mouth during repeated drilling of vertical and deviated boreholes
			Reducing the costs for explosives and hole drilling up to 10%, increasing productivity of mining machinery up to 8%, improving the rock crushing quality. Razrez "Tugnusky" JSC "SUEK" opencast - economic effect amounted to 510 million rubles [16].	Influence on related process	Explosive rupture process	Explosive application rate
						Particle size distribution of ruptured rock
					Excavation process	Excavator bucket capacity
						Loading cycle duration
						Excavator productivity
						Excavation unit costs
					Transportation process	Vehicle body space
						Vehicle cargo carrying capacity
						Unit cost of transportation
						Transport productivity
					The process of primary breaking in a crushing-and-concentrating plan	Crusher parameters (grip angle, throughput, motor power)
VI	Improvement of maintenance and repair system	Uralasbest JSC [29] Kachkanarsky GOK, other iron ore quarries	Timely decommissioning of obsolete rigs resulted in improved performance and operation safety.	Parameters of blasthole drilling process		Drilling rig performance
						Mechanical drilling speed
						Inter-repair period
						Working time utilization factor
						Operating costs
						Drilling tools durability
						Drilling process safety

3 Systematization of factors that determine the need for transition processes implementation in drilling operations

Application of the methodological approach proposed by the corresponding member of the Russian Academy of Sciences, Doctor of Technical Sciences V.L. Yakovlev [30] on the basis of previously established results revealing transitions in drilling operations, allows to perform the decomposition of the "drilling operations" subsystem on elements and systematize the factors (Figure 1) that predetermine the onset of transition processes during drilling operations. At the same time, it is important to understand their mutual influence for managing the transition processes implementation.

The factors systematization presented in Figure 1 has revealed stable recurring relationships between them; when considering, it is possible to understand the overall functioning of the "drilling operations" subsystem and determine which of the factors are independent, objective and manageable. Independent factors include external factors, the impact of which is almost impossible to rule out, such as changes in electricity tariffs, lower demand for minerals due to market oversaturation, and others.

Changes in environmental factors are restrictive. For example, changes in the minerals price, demand, inflation - all of them indirectly determine the requirements for specific consumption, the type of material and energy resources used in drilling operations, technical perfection level of the technique used, stages and duration of transition to new models of drilling rigs.

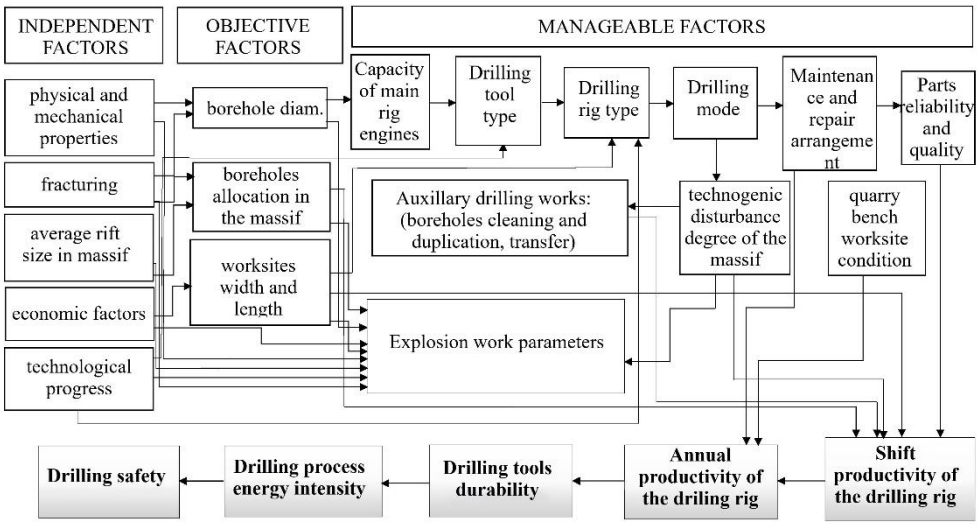

Fig. 1 Systematization of the main factors that predetermine the need for implementation of transition processes in the subsystem "drilling operations".

Objective factors significantly influence the structure and parameters of the "drilling operations" subsystem and are determined by external factors, that is independent of the activity of the enterprise. Manageable factors are interrelated with objective factors and influence the timely selection of transition processes, implementation of which becomes manageable considering previously identified inter-factorial links. This allows the necessary and enough resources to be sought in advance to improve the efficiency and safety of blasthole drilling at the quarry under changing mining conditions of minerals. The control factors include, for example, the reliability and quality of the parts applied that

affect the breakage rate of the drilling rig, the durability of the drilling tool and accordingly the safety and efficiency (productivity) of the drilling rig.

Factors systematization results accounting done by specialists of mining companies will allow for rational transition processes to stabilize or increase a certain indicator of the "drilling operations" subsystem state, for example, the shift performance of the drilling rig, take into account not only the physical and mechanical properties of rocks, but also pay attention to the quality of quarry bench worksites preparation and the impact of the technogenic disturbance degree of the rock massif, depending on the parameters of blasting (Figure 1). Based on the established systematization it is possible to envisage changes of individual factors depending on changes of others not connected by an explicit functional link at the stage of planning. For instance, the annual productivity values of the drilling rig may experience variations of a certain periodicity depending on the quality and frequency of repairs and maintenance carried out. The roller bits endurance index may change due to the erroneous prediction of the drillability grade (physical and mechanical properties) within the section (sections) and/or drilling tools inconsistency to the manufacturer's declared characteristics and/or non-compliance with operating regulations.

4 Conclusion

As a result of the studies, transition processes have been identified, preventing the negative impact of the changing conditions of developing complex mineral deposits and increasing efficiency and safety of innovations adoption in drilling technology. The main factors that predetermine the changes in conditions and the need for the transition processes implementation of drilling operations in quarries were determined and systematized. In practical terms, the research results can be applied to the auditing of drilling operations at mining enterprises with an open mode of mining and identification of rational controlled transition processes that adapt the parameters of drilling technology to changing conditions of internal and external environment.

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