General methodology for the optimization of the parameters of aggregated tunneling systems

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Abstract. The general methodology of parametric synthesis of aggregated tunneling systems determines the sequence of procedures for setting and solving the problem of obtaining an extreme value of target function taking into account the multifunctional structure of the aggregated versions of tunneling systems. ATS are presented in the form of a combination of constructive-technological modules, which allows taking into account their technological and structural features and determining energy limitations at the initial stage of iterative optimization process. This type of the representation of ATS makes it possible to formalize the target functions of structural elements (modules) of ATS, justify a set of geometric, kinematic, power and energy limitations and form a specific sequence of actions to optimize the parameters of each module and ATS as a whole.

1. Introduction
The development of aggregated tunneling systems (ATS), also called complexes, is one of the promising areas of the development of mining equipment [1]. However the methods for the determination of their optimal parameters have not been sufficiently investigated up to the present moment. Nevertheless, the choice of optimal parameters of mining equipment, including aggregated equipment, is extremely relevant in modern mining engineering. For an effective parametric synthesis of an ATS, it is necessary to form general methodological approaches to the selection of their optimal parameters with approbation through the specific examples.

Parametric optimization is an integral part of the general methodology of structural-parametric synthesis of technical solutions. The research works devoted to the optimization of the parameters of mining equipment [2–9] (including tunneling equipment) [10], use the principles of system approach and the mathematical apparatus of operations research to varying degree [11–13].

The purpose of operations research is to achieve an optimal solution which ensures the extreme value of target function under a scientifically grounded system of limitations. The methodical features of the science of operations research, taken into account during the choice of the parameters of mining complexes, are as follows. Firstly, the need for consistent implementation of the main stages of research: the choice of target function; the justification of the system of limitations; the development of mathematical models of the process with the definition of necessary information to them; the achievement and analysis of optimal solution. Secondly, the compulsory applications of the fundamental principles of a systematic approach, consisting in the need to take into account the changes in system operation when it affects its elements.

For this purpose, it is necessary to identify significant intra-system communications which may be
affected during the choice of a specific technical solution of ATS.

2. The features of the statement and solution of the problem of parametric synthesis of ATS

If the above mentioned sequence of the main stages is observed, the task of the optimization of the parameters of ATS acquires the character of a typical one. However, a detailed examination reveals the essential features:

1. ATS are developed for the use in a certain application area and without specifying it, the choice of optimal parameters is impossible. There is a controversial situation when in order to find the optimal parameters it is necessary to know the scope of the complex, and it depends on its parameters. The solution of this problem is possible by the method of successive approximations (iterations): the required conditions for the use of ATS are assigned; the optimization of parameters (the 1st cycle); for the obtained parameters, the possible conditions of use are specified; in case of their inconsistency with the required ones, the conditions of application are specified, and the optimization is performed under the changed conditions (the 2nd cycle) and it repeats until the area of possible conditions does not match the required one (Figure 1).

2. The most important feature of ATS is their multifunctional structure. Each ATS has several interconnected parts, each of which performs one or several functions. ATS have different structures and conditions of interaction of technological subsystems (modules). In contrast to individual mining machines, for example, loading ones, the optimization of the parameters of ATS should be performed both for the system as a whole and for individual elements - basic, intermediate and functional [1]. In this case, the global target function of the entire system should reflect the effectiveness of ATS at the output. The target functions of individual subsystems and ATS as a whole must comply with each other. The subsystems or elements used in several processes may have different requirements on the part of the elements interacting with them. The global target function of ATS may be presented by performance, energy intensity or unit costs. The target functions of individual subsystems (modules) can be similar, their extreme values will not contradict the global target function, and however, the constraint systems will differ. The power supply of the modules will also be different, which will require individual solutions to be found in each specific case.

3. General methodical approach to the statement and solution of the problem of parametric synthesis of ATS

Taking into account the above mentioned features, a general methodical approach to the statement and solution of the problem of parametric synthesis of ATS was developed. It is presented in the form of an integrated algorithm for the iterative process of the selection of optimal parameters of ATS (Figure 1). Next, let us consider the content of each block of the algorithm with the necessary justification.

Block 1. Process onset

Block 2. Initial data input: the structural formula of ATS, selected on the basis of the results of structural synthesis [1] and representing ATS as a set of interrelated structural elements which perform the destruction of bottom, loading and transportation of rock mass, fixing production and technological movements of equipment; required conditions (scope) of the application of ATS, as specified by a customer.

Block 3. The development (on the basis of a structural formula) of a kinematic interaction model (KIM) of structural elements (in the form of constructive-technological modules), indicating the functions performed by them, the executive bodies and the types of drives of their working movements (a single drive providing energy for the entire ATS; individual drive of particular executive bodies; group drive of several executive bodies). KIM is necessary for specifying parametric optimization objects. Figure 2 shows the generalized structural formula of ATS [1], and Figure 3 shows the generalized KIM, based on the generalized structural formula. An intermediate element (IE) in them is the device created to perform a single function — the movement of functional elements (FE) relative to the basic element. Therefore, the functions performed by IE are not included in KIM.
Figure 1. Integrated algorithm of the iterative process of the selection of optimal parameters of ATS with free structure.
Figure 2. The generalized structure of ATS in the form of a structural formula: (a) in the presence of kinematic relations; (b) in the presence of constructive and kinematic relations; FE – functional element (module); n – the number of types of FE; IE – an intermediate element; m – the number of IE; BE – the basic element (a device developed to move the associated FE and IE relative to the current development); “+” – kinematic connection; “•” – constructive relationship

Figure 3. Generalized model of kinematic interaction of ATS modules.

Block 4. The development of conditional time schedule for the operations of driving cycle, which reflects their sequence and possible combination. It is necessary to establish the conditional share of the performance of ATS created by each module, as well as to select the target functions of each module.
Block 5. The choice of global target function of ATS and target functions of structural and technological modules. It was already mentioned above, when describing the second feature of the optimization of the parameters of ATS.

The blocks from 6 to 14 relate to the iterative part of the process, the essence of which is described in the description of the first feature of the parametric optimization of ATS.

Block 6. The determination of dimensional limitations of entire ATS necessary for seamless placement of the complex in the required range of cross sections of mine workings.

Block 7. The determination of energy limitations, i.e. the maximum energy availability of the entire ATS as a whole and its individual modules based on the types of drives which were previously defined in the preparation of KIM (block 3). In the same block, a preliminary selection of energy supply sources (engines, pumping stations) from models produced by industry is carried out, since it is the power which determines the possibilities of achieving maximum performance and other quality indicators to the greatest extent.

Block 8. On the basis of the structure and technological features of ATS, the target functions and the basic limitations selected in blocks 5-7, for each module, the limitations of the following groups are determined: geometric, necessary for the equipment to function seamlessly, such as drilling holes, loading masses, etc.; kinematic, limiting, for example, the allowable linear velocity of movement of the working elements and other structural elements; power, establishing maximum efforts which can be developed in mechanisms; energy, determining the inadmissibility of exceeding the installed capacity of engines, taking into account the mode of their operation.

The parameters included in the limitation system and affecting the value of the target function are often objects of optimization. The procedure for the determination of the list of parameters to be optimized requires knowledge of the regularities of the working processes implemented in every module. Therefore, the preparation for this procedure should include either the development of mathematical models of working processes (for new equipment), or the search and analysis of existing mathematical models (for existing equipment) with the definition of the necessary information to them, including the limits of variation of factors, the rationale for options for their combinations etc.

Block 9. The procedure for the determination of optimal parameters of the modules includes: the development of a plan for the computational experiment (for a new equipment); the development (the use of existing) of the program for calculating performance indicators for each module, for example, the performance of transportation of rock mass, the duration of drilling holes, loads, power, etc.; the performance and evaluation of calculation results, the determination of residual resources and adjustment of computational experiment plan.

Block 10. On the basis of optimal parameters of the modules obtained in block 9, the final selection of the parameters of ATS as a whole is made.

Block 11. For the selected parameters, possible conditions for the use of ATS are specified. They may be wider or narrower than a desired scope.

Block 12. The comparison of the required conditions (areas) of application of ATS with possible conditions corresponding to the obtained optimal parameters. In the case when the obtained conditions correspond to the required ones, an additional iterative cycle is not required and the solution of the optimization problem is completed in block 14.

If there is no such correspondence, then the researches proceed to Block 13, in which the required conditions (scope) of ATS are clarified. The decision maker is usually a customer. In the case when the obtained possible conditions for the application of ATS satisfy a customer, the process of the optimization of parameters is completed. Otherwise, a customer either adjusts the required conditions, bringing them closer, if possible, to the received ones, or leaves them unchanged. In either case the process returns to Block 6 and repeats until the conditions of use of the complex correspond to the required ones.

4. Conclusion
1. On the basis of the principles of systems approach and the mathematical apparatus of operations
research, a general methodology of parametric synthesis of ATS was developed, which includes a sequence of procedures for the statement and solution of the problem of achieving extreme values of the target function and takes into account the multifunctional structure of aggregated variants of tunneling systems.

2. ATS are presented as a set of structural-technological modules. It allows taking into account their technological and structural features and to determine the basic energy limitations at the initial stage of the iterative optimization process. Such a representation of ATS makes it possible to formalize the target functions of the structural elements (modules) of ATS, justify the geometric, kinematic, power and energy limitations and form a specific sequence of actions in order to optimize the parameters of each module and the ATS as a whole for any possible structure of ATS and the specific conditions of its operation.

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