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Utilisation of the Simulated Annealing Method for optimisation of configuration of cutters on the cutterhead

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ABSTRACT

The paper deals with the application of a new mathematical method to achieving optimum configuration of cutters fixed on cutterheads of winning machines. This method has not been used in this field yet; it significantly simplifies the labour-intensive process of determination of positions of cutters on a cutterhead.

KEYWORDS : cutterhead, optimisation, simulated annealing

Introduction

Optimum positioning of the cutters allows us to achieve reduced wear and consumption of the cutters as well as reduced dynamical stress on the machine, increased output of the machine and longer life of the cutterhead and entire machine. It even brings down energy demands of the winning machine.

Analysis of configuration of cutters on a cutterhead

The design of optimum configuration of cutters must be based on a criterion of uniform load acting on all cutters fixed on the cutterhead. Today's cutterheads have some cutters which are loaded excessively, whilst there are other cutters which are integrated into the disintegration process very little or even not at all because they move in a lined-up configuration.

Currently configuration of cutters on a cutterhead is analysed using the TOOLHEAD JVJS program system allowing mathematical modelling of the sub-system consisting of the cutterhead and rock being disintegrated. The calculated variation of dynamic forces and moments in relation to a relative coordinate system of the cutterhead are applicable, after transformation, to investigation of the dynamic effect of the overall system of the winning machine.

"Cutting Pattern" – a new program with application of the Simulated Annealing Method

"Cutting Pattern", a new program for designing the cutting pattern of a cutterhead, was developed in a way allowing changes of the geometry of a cutter. In addition, the program allows the particular rock being disintegrated to be assigned even the assumed natural rock failure or the water beam passing through the centre of the cutterhead to be displayed in graphic form. The program has the aim of contributing to optimisation of the process of disintegration through improvement of both configuration of positions of cutters and overall design of the cutterhead.

The results obtained by the optimisation methods of this program have been verified using the TOOLHEAD JVJS program system.

The new program „Cutting Pattern" has been developed in the Borland Delphi environment and is run in the Windows system, platform PS. This paper provides information on initial utilisation of the Simulated Annealing Method for optimisation of cutters on a cutterhead of a winning machine in relationship with the TOOLHEAD JVJS program system.

Analysis of rock disintegration with cutters on cuterheads of winning machines

4.1. Cutting pattern

The cutting pattern shows projections of cutters in ρ_{xy} plane (Fig.1). The axis of the cutterhead is identical with the X -axis of the co-ordinate system. The co-ordinate system origin 0 is selected at a point where $x \geq 0$ applies to all points on the cutterhead. The vector v_p of the advance rate of the cutterhead is identical with the positive direction of the y -axis.

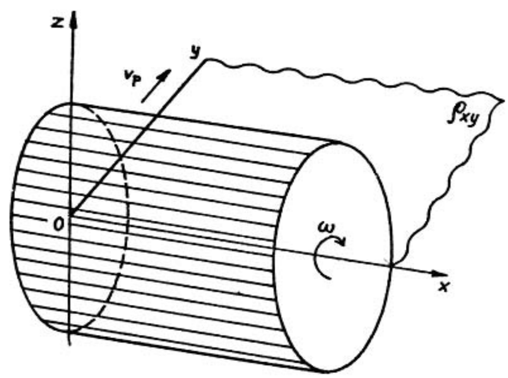

Fig.1: Position of the cutterhead within a 3-dimensional coordinate system

x,y.z – axes of the rectangular coordinate system, *0* – origin of the coordinate system *xyz*, ρ_{xy} – quadrant of the plane determined by the axis or the cutterhead rotation (identical with x-axis) and the direction of the advance of the winning machine v_p, ω - angular velocity and direction of the cutterhead rotation.

The set of the number of projections of cutters in a point of ρ_{xy} plane is denoted by the term **point coverage**. A point which is covered by none of the cutters is assigned 0; a point covered just by one cutter is assigned 1; a point covered by 2 cutters 2, etc. An approach based on the idea that e.g. the coverage 1 is excellent, 0 and 2 is not good and coverage 3, 4, 5 and higher is more than bad allows us to develop a model of **assessment of the point** that is an arbitrary function of the point coverage.

The point coverage required for various rock mass types to be disintegrated differs. The cutters which are positioned on the cutting-off plate disintegrate the rock (coal) at the largest distance from the free excavation face, therefore they work in the sector where they are exposed to excessive forces. Cutters positioned on helices work in a sector exposed to more favourable action of forces because they are closer to the free excavation face. The cutters positioned between the cutting-off plate and the helices have a special assignment because they must provide effective transition between both above-mentioned sectors.

Depending on the thickness and character of coal seams (with and without intercalations, variable thickness, occurrence of tectonic faults etc.), the cutterheads of winning machines are designed with one helix up to four helices.

In the sector of helices the cutters work in more convenient conditions than in the sector of the cutting-off plate. Therefore the cross sections through the cutting grooves are substantially larger. The cutters are positioned along helices so that they create a staggered configuration of the cutting. This allows achievement of more suitable grading of muck together with reduced power consumption.

When seams with intercalations, which are more difficult to disintegrate, are being disintegrated, cutters on multi-helix cutterheads (with two, three or four helices) can be positioned so that two or even more cutters work along one cutting line. The character of the cutting profiles is that of deepening cutting grooves. Power consumption for the disintegration is significantly higher, disintegration outputs are lower and the grading of muck substantially worse compared with the staggered configuration of the cutting lines.

4.2. Cutterhead quality assessment

Knowledge of a method of unambiguous assessment of quality of a cutterhead is necessary for the needs of optimisation of mechanical equipment. The most suitable means of the assessment is a representation system which assigns just single scalar quantity to each configuration of the cutterhead. This quantity is called fitness (viability).

One of possible representations of the configuration of the cutterhead in the fitness is the integral of the assessment of all points of the cutting pattern.

4.3. Simulated Annealing

Simulated Annealing is the Monte Carlo method for minimisation of a function of more variables. Its name is derived from a similar physical process existing in nature: the process of heating and gradual cooling of material, which results in the development of a firm crystalline structure.

We will introduce the property called "temperature" (T) to the system being investigated. The value of this property expresses the maximum probability we will assign to the possibility of transition to a worse condition compared with the preceding condition, when we move within the space determined by the input variables. At the beginning of the process of cooling, the temperature is set to a certain selected value and the input variables of the investigated function f are filled with random values. Until the temperature drops under a certain limit (the "freezing" temperature), we continue carrying out the following iteration step: the values of the input variables are randomly changed (within a certain predetermined interval) and the new value of the function f is calculated. If the new value is lower than the original, we will accept the new set of values of the variables as correct. If it is higher, we will do it using the probability

$p = e^{-\frac{\Delta f}{T}}$, where Δf is the difference between the new and original value f. At the end of the iteration step we carry out the cooling by reduction of the temperature $T \leftarrow T \cdot coef$, where $coef$<1 is the cooling coefficient.

4.4. Utilisation of the Simulated Annealing Method for optimisation of configuration of cutters on the cutterhead

The Simulated Annealing Method can be utilised for optimisation of the configuration of cutters on the cutterhead. Configuration of the cutter is the vector $\vec{n}(\vec{R}, X, \varphi, \alpha, \beta, \gamma)$. Configuration of the cutterhead is then expressed by $\vec{k}$, which is the vector of configurations of individual cutters.

$$\vec{k}(\vec{n}_1, \vec{n}_2, ..., \vec{n}_n)$$

The simulated annealing (condition assessment) is based on the fitness value, which is functionally dependent on the configuration vector $\vec{k}$, therefore can be denoted by $E(\vec{k})$. The optimisation algorithm improves quality of the configuration by means of random changes introduced with the aim of improving the $E(\vec{k})$ (which may, depending on the definition of the fitness representation, mean both an increase or decrease in the numerical value $E(\vec{k})$).

4.5. An example of the utilisation of the Simulated Annealing Method for optimisation of configuration of cutters on the cutterhead

The „Cutting Pattern" program contains modules for calculation of the coverage and assessment of points of the cutting pattern and for optimisation of the cutterhead based on these values using the Simulated Annealing Method (Fig. 2).

The survey of basic data is arranged in the entry form, which contains data on individual cutters fixed on the particular cutterhead.

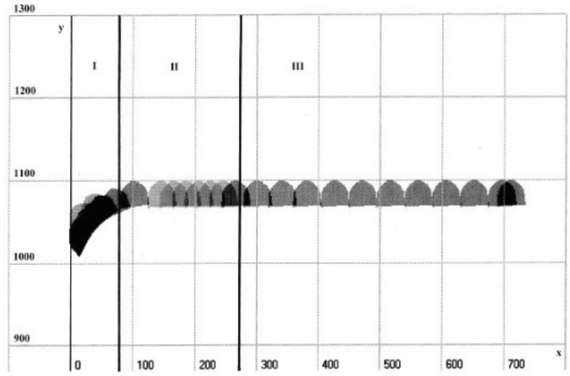

Fig. 2: An example of application of the Simulated Annealing Method to optimisation of the configuration of cutters on a cutterhead

The results obtained using the optimisation methods of this program have been verified by means of the TOOLHEAD JVJS program system.

Both the nonoptimised cutterhead and optimised cutterhead were analysed. The comparison of the cutterheads clearly showed that the diagrams of forces and moments per revolution of the cutterhead are significantly better poised after the optimisation.

Well poised diagrams of forces and moments that originate on the cutterhead in the course of the disintegration action mean positive affection of dynamic stressing of the winning machine.

Conclusion

It follows from the completed analysis that the proposed Simulated Annealing Method is a step, which offers a new way to improve the process of optimisation of configuration of cutters. When further improved, it can result into a comprehensive multi-parameter system of optimisation of configuration of cutters, which could significantly contribute to the efforts to reduce the level of dynamic load on cutterheads of tunnelling and winning machines during the rock disintegration process.

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