The influence of advancing speed of powered mining stope with single face on earth's surface displacing in Kuzbass

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Abstract. The researches in the area of undermined rock massifs estimate the influence of advancing speed of mining stopes on earth's surface shifting ambiguously. It reflects the lack of maturity of this trend. The aim of this paper is to establish the relationship between subsidence of individual points on the surface profile line along strike and the speed of stope's advancing, taking into account other influencing factors. Dependencies of displacement of certain points of the earth's surface undermined during mining operations can be identified by frequency instrumental observations on the profile lines. Further analysis is made by mathematical methods, including the random number theory. In the formation of the dynamic downfold of displacement the relationship between advancing speed and subsiding of individual points in the "behind the face" half-downfold cannot be traced. In the "front face" half-downfold the increase of mining stope advancing speed reduces dynamic subsidence. In the paper empirical relationships between subsidence of individual points on the surface and the position of the working face were shown.

1 Introduction

The Earth's surface is the part of a deformable earth formation, and its displacement reflects the processes that occur in undermined rock mass. Note the hypotheses that were confirmed in the current schemes and mechanisms of displacement of undermined earth formation:

- The rule of "normal", introduced by Gonot [1] and further developed by Dumont [2], is based on the seam's roof decomposition on the following components: the normal to the bedding and the normal acting along the seam, which is balanced by the reaction of the underlying rocks. Based on this postulate, the roof displacement will occur only under the influence of the normal component;

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- The "arch" hypothesis, which are based on the fact that the collapse of rocks in the roof of workings is shaped like an arch. One of the first "arch" hypotheses was proposed by Ritter [3] and then developed by Fayol [4];

- "Beams" hypothesis was proposed in 1867 by Schultz [5]. Rock layers over the worked-out area represented by the solid layered rocks are treated as the beams, embedded with one end in pillar. The other ends of the beams can lean on the supports, backfilling or even hang freely. The roof, consisting of several layers of rock, is considered as a set of beams.

The final stage of the early period of displacement researches and at the same time the beginning of a new period was Briggs theory [6], where for the first time the rock mass was considered as a medium in the volumetric stressed state.

Despite a long history of domestic and foreign scientific researches in the strata displacement, there is no single scientifically sound theory, revealing the inner essence of the phenomena and derived therefrom methods for calculating the deformation of containing rocks and the earth's surface.

2 Materials and Methods

The first methods of calculation of Earth's surface subsidence at a small depth of coal seams mining were based on data obtained from the opinion made upon observations that subsidence depends on the thickness of a mined seam m and its dip angle α: $\eta_Z = m \cdot \cos \alpha$. On the mines of Essen the scale of earth's surface subsidence was estimated by the formula: $\eta_Z = n \cdot m \cdot z$ w, here the coefficients n and z were used for considered method of coal extraction (with the collapse of the roof or with backfilling of worked-out space) and the time elapsed after the ending of mining works. The coefficients considering the depth of mining works and the extent of undermined rocks disintegration were introduced later [7].

As a result of further instrumental observations the scholars began to consider the area of the mined segment in their calculations - first by introducing a "reduced" thickness of mined seam m_{red} [8], and then with use of the coefficient equal to the ratio of mined segment area to the area of the influence of mining operations on the earth's surface [9].

After World War II new directions in the science of strata displacement appeared: stochastic method, displacement calculation on standard curves, finite element method which are widely used now. Today, there are a lot of programs that implement the finite element method: NASTRAN, ANSYS, MARC and others.

Embodiments of the method of standard curves were developed in Poland, Hungary, Germany and the USSR, where it became principal and entered the current regulations on the calculation of displacements and deformations of the earth's surface.

Nevertheless the number of papers devoted to dynamic processes accompanying the active phase of undermining earth's surface displacement, is small enough in general, including the area of cognition research of geomechanical processes that indicate a lack of maturity in this direction.

The complexity of the problem of dynamic manifestations of rocks subsidence in undermining by fast moving mining faces is illustrated by the fact that even today the impact of stope advancing speed changes on the geomechanical processes occurring in the array at high speeds of undermining is estimated ambiguously.

A number of researchers, basing on the observations of the displacement of rocks and the earth's surface under the influence of mining works indicate that the increase in mining stope advancing speed in many cases reduces the deformation of the earth's surface. Others argue that the rate of stope advancing has no significant effect on the earth's surface defor-

mation, but increases or decreases the duration and intensity of the displacement process. Taking into account that the rate of face's stope advancing over which the subsidence of Earth's surface was previously observed does not exceed 100 m per month, and varied considerably little, its unnoticed influence on the process of the earth's surface displacement can be assumed. However, if we consider the currently existing displacement speed values, the conclusion of non-essential role of the speed seems premature.

If 15-20 years ago, the stopes advancing speed rarely exceeded 150 m per month, then now they have reached 450 m per month and more. At the current load on mechanical systems, which some day reaches 20000 tons, the stopes advancing speed can be expected up to 600 m per month. In this regard, the special attention should be paid to the studies by A.S. Yagunov on displacements and deformations of the earth's surface for the high speed of face's stopes advancing (up to 15 m per day) in Kuzbass. He examined the dynamics of displacement downfold profile formation depending on stope advancing. At the same time the following terms were introduced:

- *the dynamic displacement downfold* - the state of displacement downfold in the process of its formation, depending on the position of the working stope of the face to the mounting chamber;

- *the dynamic displacement micro-downfold* - the state of displacement downfold at the withdrawal of the stope from the mounting chamber to the "flat bottom" formation;

- *the dynamic subsidence of the Earth's surface* η_d (mm, m) - vertical component of the displacement vectors of displacement the points in the dynamic downfold depending on the position of stope of the face to the mounting chamber;

- *the dynamic horizontal displacement of the Earth's surface* ξ_d (mm, m) - the horizontal component of the displacement vectors of the points in the dynamic downfold depending on the position of stope of the face to the mounting chamber;

- *the half-downfold behind the stope* L_{bs}– the half-downfold from the side of mounting chamber;

- *the half-downfold in front of the stope* L_{fs}- respectively from the side of dismounting chamber.

As a part of the development of theoretical ideas about the dynamics of displacements and deformations at flat and inclined coal seams processing by high-productive stopes in Kuzbass mines many various monitoring stations were founded. Each of the monitoring stations consisted of two profile lines of ground frames laid down in the directions of strike and across the strike of the faces. As the frames the metal rods were used (length -1.8 m and diameter - 20-22 mm) forged on the spearhead. The frequency observations were carried out with a periodicity of 1 time in 2 days. The observation results were processed using statistical methods and correlation analysis.

3 Results and Discussion

This article presents some results of studies of the influence of powered face's stope advancing speed during flat and inclined coal seams mining in Kuzbass on the dynamics of individual points of the undermined Earth's surface. The terminology introduced by A.S. Yagunov is retained. It is found that the character of displacement points on the Earth's surface in the plane $\xi 0 \eta$ the dynamic downfold profile along the strike is divided into four zones A, B, C and D (Fig. 1). Their dimensions were defined accordingly the border angles δ0, δ'0 and the angles of characteristic zones δA , δB, δC, δD, established by instrumental observations.

The regularities of points of the Earth's surface subsidence changes in the specific areas (*xs*) A, B, C and D depending on the current situation of the mining stope (*lt*) in the interval

$D_{2x} = 1.6 H_{cp}$ were defined. Initial data of instrumental observations were presented in the normalized form. The transition from conventional to normalized units was done using linear normalization performed within the variables [0, 1] by formula (1):

$$x_{нik} = \frac{x_{ik} - x_{\min k}}{x_{\max k} - x_{\min k}} , i = 1, 2, …, n; k = 1, 2, …, N \tag{1}$$

where: x_{ik}, $x_{нik}$ - value of the variable in the traditional dimension and in a normalized form in the *k-th* sample; $x_{\min k}$, $x_{\max k}$ - the minimum and maximum values of a variable in the *k-th* sample; n - the number of data in the *k-th* sample; N – the number of samples.
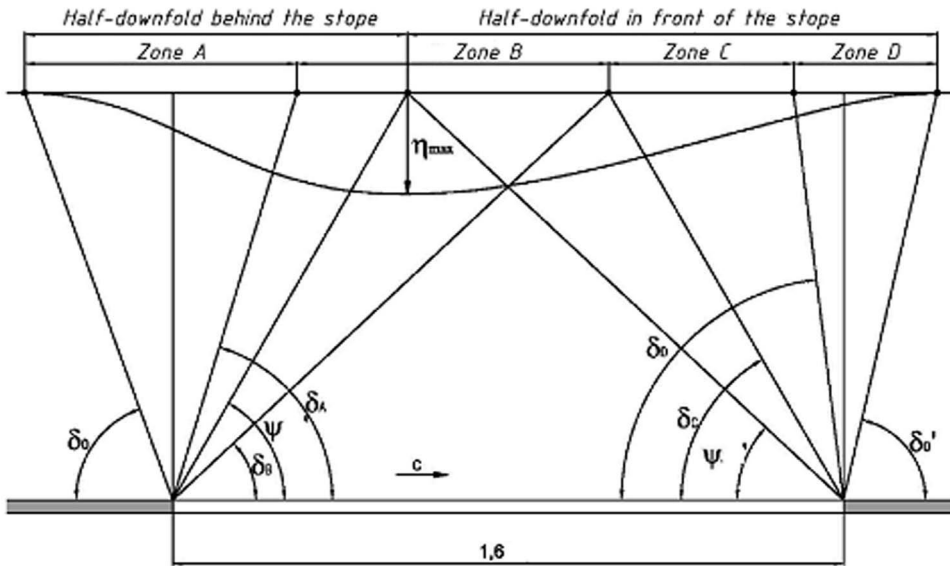

Fig. 1. Subsidence zones A, B, C and D in formed micro-downfold for mining stope position $D_{2x} = 1.6 H_{cp}$ in the section across the face's strike.

Fig. 2 shows the calculation of expected subsidence and horizontal displacement of the surface point in zone B. Face with 200 m width, 1000 m length and with an average depth 200 m at advancing the stope with the speed 5 and 15 m per day is being worked. The dip angle of the coal seam is 10˚, extracted thickness is 3 m.

The point being evaluated is at a distance of 270 m from the mounting chamber in zone B. Subsiding of the point begins at the position of stope at 160 meters from the mounting chamber and occurs as a sigmoid to a maximum (η_{max}) of 1450 mm for c = 5 m per day, and 1193 mm for c = 15 m per day. Horizontal displacement of point depending on the scale of subsidence can be treated as reciprocating. First the point moves towards dismounting chamber up to a maximum of ξ_{max} = 244 mm decreasing exponent, then increasingly shifts exponent in the direction of mounting chamber. Advancing speed of the stope does not affect analytical dependence of horizontal displacement on the point's subsiding. It depends only on the value of the final subsiding.
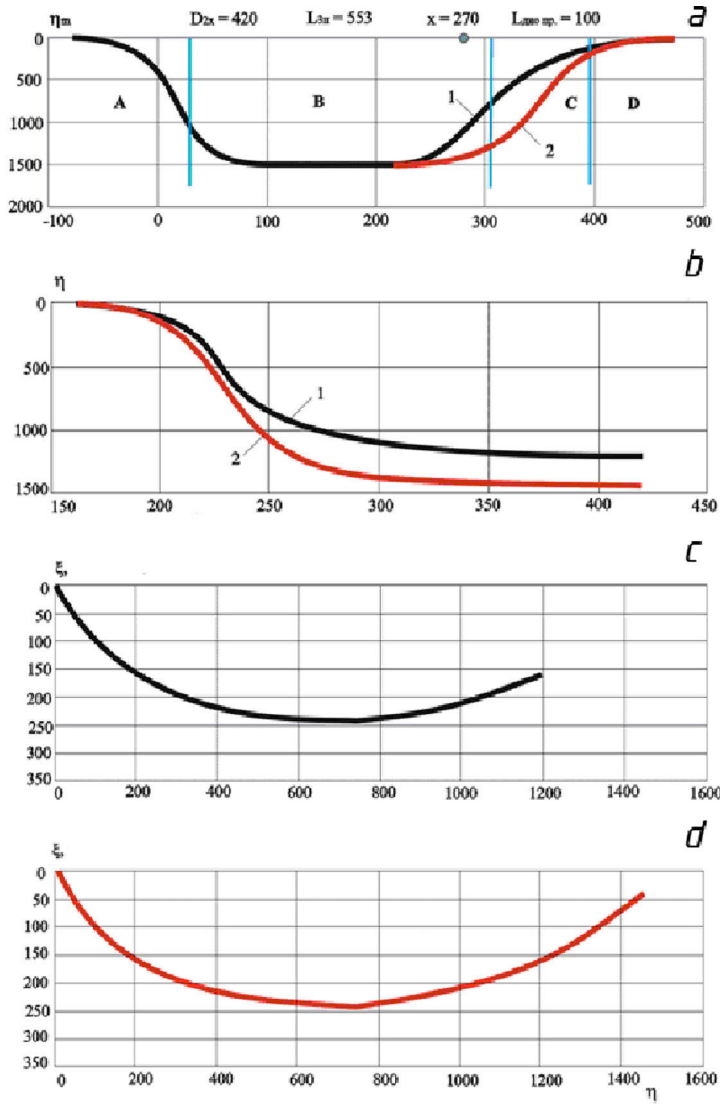
Fig. 2. The calculation for example: a) dynamic displacement downfold for mining stope withdrawal of 420 m from the mounting chamber; b) the pattern of surface points subsidence distant from mounting chamber of $x = 270$ m; c) horizontal displacement of the point depending on the subsidence for advancing speed of stope (*c*) of 5 m per day; d) horizontal displacement of the point depending on the subsidence for advancing speed of stope (*c*) of 15 m per day.

4 Conclusions

The growth of advancing speed of the stope (up to 15 m per day) does not have significant influence on the final value of the Earth's surface deformation, but only reduces their dynamic values in intermediate half-downfold close to mounting chamber, i.e. increase in speed changes the intensity of displacement process in "front face" half-downfold. The half-downfold by dismounting chamber flattens when advancing speed of the stope increases. That reduces the value of dynamic subsiding of the point in this area of undermined

surface. Obtained analytical dependences of horizontal displacement of the surface point on the value of its subsiding in characteristic zones A, B, C and D does not change with increasing advancing speed of the stope.

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