Assessment of the Impact Hazard of the Array Taking Into Account the Geological Features of the Structure of Electric Profiles

Konstantin Dudko\textsuperscript{1}, Alexey Shikanov\textsuperscript{1}, and Yuri Lesin\textsuperscript{1}

\textsuperscript{1}T.F. Gorbachev Kuzbass State Technical University, 650000, 28 Vesennyaya St., Kemerovo, Russia

Abstract. The current geodynamic situation at the Tashtagol iron ore Deposit is considered. The impact hazard of the array was determined using electrometric coefficients obtained taking into account the geological structure of the array. An assessment of the correspondence of the obtained coefficients to actually registered geodynamic phenomena was made.

1 Introduction

The experience of mining all ore deposits in Western Siberia shows that with increasing depth of mining operations, there is an increase in the intensity and frequency of manifestations of mountain pressure in a dynamic form. The most representative in terms of manifestations of dynamic phenomena is Tashtagolskoe field.

A total of 595 events with an energy of more than 100 J were recorded at the Tashtagolsky mine during the period from February 2018 to August 2019 within the horizon (-350), with more than 70\% of them occurring below the horizon (-300). Their distribution by month and energy class is shown in table 1. At the same time, during the period under review, there is an increase in cases of mountain pressure manifestations in the workings, and there is an increase in energy and the approach of the foci of events to the workings.

Table 1. Distribution of geodynamic events by month and energy class within the horizon (-350) for the period from 01.02.18 to 30.08.19.

| Date         | Energy class of a geodynamic event | Violation of fastening of mine workings | Total |
|--------------|-----------------------------------|----------------------------------------|-------|
|              | 2 3 4 5 6 7                        |                                        |       |
| February 2018| 27 4 1 - - -                         | -                                      | 32    |
| March 2018   | 6 - - - -                           | -                                      | 6     |
| April 2018   | 8 2 - - -                           | -                                      | 10    |
| May 2018     | 4 3 1 - -                           | -                                      | 8     |
| June 2018    | 9 6 2 1 -                           | -                                      | 18    |
At the same time, during the period under review, there is an increase in cases of mountain pressure manifestations in the workings (table 2), and there is an increase in energy and the approach of the foci of events to the workings.

Table 2. The manifestation of rock pressure.

| Geodynamic events | Date       | Energy, J   | Energy class | Manifestation of the rock pressure          |
|-------------------|------------|-------------|--------------|--------------------------------------------|
| 1                 | 28.02.2018 | 1442374     | 6.2          | Violation of fastening of mine workings     |
| 2                 | 06.02.2019 | 5516.046    | 3.6          |                                            |
| 3                 | 26.03.2019 | 365907.4    | 5.6          |                                            |
| 4                 | 17.05.2019 | 35910.68    | 4.6          |                                            |
| 5                 | 16.06.2019 | 14762.41    | 4.2          |                                            |
| 6                 | 30.06.2019 | 2190742     | 6.3          |                                            |
| 7                 | 21.07.2019 | 70076416    | 7.8          |                                            |
| 8                 | 16.08.2019 | 41717324    | 7.6          |                                            |

Currently, at the mines, in particular, at tashtagolskoye, for the regional forecast of the degree of impact hazard of the array, it is carried out mainly by methods of Electrometry and microseisimics. The foreign experience of recent years is mainly limited to the coal deposits of China and Poland [1-10] and is based on the study of similar individual issues, while focusing on the technology of mining and the mechanism of formation of a mining shock, rather than its forecast. The impact hazard of the array during electrometric measurements at the
first stage is determined by the value of the electrometric coefficient \( K^*_\rho = \frac{\rho_e}{\rho_n} \), where \( \rho_e \) - the average value of the CUES for the entire measuring profile or for each structural block, \( \rho_n \) - the average value of CUES in the absence of geodynamic phenomena. When the coefficient is set \( K^*_\rho < 1 \) in controlled workings, special measures are taken to identify impact-prone areas of the array.

2 Theoretical part of the question

However, the iron ore deposits of the Mountain Shoria are represented by a large number of vertical or steeply falling contacts between rocks that compose the array around the mine workings, and the electric profile lines laid along their sides intersect a set of fairly well-defined vertical (steeply falling) rock layers. When an electric current flows or electromagnetic waves propagate through a layered medium, reflection and refraction phenomena are observed at the contacts of the layers, which affects the distribution of the CUES along the measuring profile. Thus, this array should be represented as an alternation of vertical homogeneous isotropic layers of rocks [11-13]. If the electrical resistance of the \( i \) – th layer is equal to
\[
R_i = \rho_{ki} / h_i ,
\]
then the entire layered array should be represented as a parallel connection \( n \) resistors with resistance \( R_i \) each layer. Then the total (equivalent) resistance of the array \( R_{equ} \) will be equal to:
\[
\frac{1}{R_{equ}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} = \sum_{i=1}^{n} \frac{1}{R_i}
\]
Subject to (1) formula (2) will take the form:
\[
\rho_{k(equ)} = \frac{\sum_{i=1}^{n} h_i}{h_1 + h_2 + \ldots + h_i}
\]
A similar approach to accounting for the number of layers and replacing their set with one equivalent is used in the theory of grounding devices, especially when designing grounding and lightning protection systems.

3 Results and discussion

Using the formula (3), the electrometric measurements were recalculated for all controlled workings (Cargo and Empty crosscut, South-Eastern field drift) on the horizon (-350). Table 3 shows the results of this recalculation and a comparison of the obtained electrometric coefficients based on the arithmetic mean of the CUES \( K^*_\rho \) and taking into account the geological structure of the array \( K^*_{\rho e} \).
Table 3. Results of recalculation and comparison of electrometric coefficients Tashtagolsky mine for the period from 01.02.18 to 30.08.19.

| Date of measurement | South-East field drift | Cargo crosscut | Empty crosscut |
|---------------------|------------------------|----------------|----------------|
|                     | $K_{\rho}^{**}$ | $K_{\rho}^{*}$ | $K_{\rho}^{**}$ | $K_{\rho}^{*}$ | $K_{\rho}^{**}$ | $K_{\rho}^{*}$ |
| 14.02.2018          | 0.51                 | 1.48           | 0.41           | 0.69           | 1.04           | 1.31           |
| 13.03.2018          | 0.37                 | 1.07           | 0.25           | 0.43           | 0.91           | 1.10           |
| 07.05.2018          | 0.62                 | 1.13           | 0.39           | 0.77           | 0.61           | 1.04           |
| 05.06.2018          | 0.30                 | 1.00           | 0.22           | 0.43           | 0.36           | 0.66           |
| 02.07.2018          | 1.68                 | 2.19           | 1.70           | 2.11           | 0.90           | 1.48           |
| 30.07.2018          | 2.40                 | 3.08           | 0.44           | 0.53           | 1.52           | 2.36           |
| 07.08.2018          | 0.82                 | 1.46           | 0.99           | 1.34           | 0.38           | 1.06           |
| 14.09.2018          | 0.66                 | 1.07           | 0.71           | 1.08           | 0.31           | 0.77           |
| 04.10.2018          | 1.76                 | 2.27           | 0.85           | 1.30           | 0.34           | 0.83           |
| 23.11.2018          | 1.09                 | 2.01           | 1.28           | 1.63           | 0.42           | 1.12           |
| 04.12.2018          | 2.87                 | 3.04           | 1.95           | 2.13           | 0.84           | 1.31           |
| 10.01.2019          | 0.53                 | 1.15           | 0.45           | 0.90           | 0.31           | 0.98           |
| 07.02.2019          | 1.07                 | 1.66           | 0.63           | 1.24           | 0.23           | 0.81           |
| 05.03.2019          | 0.85                 | 1.33           | 0.40           | 0.43           | 0.43           | 0.67           |
| 02.04.2019          | 0.75                 | 1.25           | 0.42           | 0.94           | 0.27           | 0.98           |
| 27.05.2019          | 0.37                 | 0.88           | 0.33           | 0.89           | 0.69           | 1.13           |
| 10.06.2019          | 0.27                 | 0.72           | 0.56           | 1.21           | 0.49           | 1.07           |
| 02.07.2019          | 0.60                 | 0.98           | 0.75           | 1.24           | 0.60           | 1.01           |
| 23.08.2019          | 0.40                 | 0.80           | 0.27           | 0.63           | 0.40           | 0.71           |

Electrometric values of the coefficients $K_{\rho}^{**}$ on average, by 40%, and in some cases by 70% reduced, compared to $K_{\rho}^{*}$. The quantitative distribution of the obtained qualitative characteristics of the impact hazard of the array is presented in table 4.
Table 3. Results of recalculation and comparison of electrometric coefficients Tashtagol mine for the period from 01.02.18 to 30.08.19.

| Date of measurement | South-East field drift | Cargo crosscut | Empty crosscut |
|---------------------|------------------------|----------------|----------------|
|                     | **ρ**                  | **ρ**          | **ρ**          |
| 14.02.2018          | 0.51                   | 1.48           | 0.41           |
| 13.03.2018          | 0.37                   | 1.07           | 0.25           |
| 07.05.2018          | 0.62                   | 1.13           | 0.39           |
| 05.06.2018          | 0.30                   | 1.00           | 0.22           |
| 02.07.2018          | 1.68                   | 2.19           | 1.70           |
| 30.07.2018          | 2.40                   | 3.08           | 0.44           |
| 07.08.2018          | 0.82                   | 1.46           | 0.99           |
| 14.09.2018          | 0.66                   | 1.07           | 0.71           |
| 04.10.2018          | 1.76                   | 2.27           | 0.85           |
| 23.11.2018          | 1.09                   | 2.01           | 1.28           |
| 04.12.2018          | 2.87                   | 3.04           | 1.95           |
| 10.01.2019          | 0.53                   | 1.15           | 0.45           |
| 07.02.2019          | 1.07                   | 1.66           | 0.63           |
| 05.03.2019          | 0.85                   | 1.33           | 0.40           |
| 02.04.2019          | 0.75                   | 1.25           | 0.42           |
| 27.05.2019          | 0.37                   | 0.88           | 0.33           |
| 10.06.2019          | 0.27                   | 0.72           | 0.56           |
| 02.07.2019          | 0.60                   | 0.98           | 0.75           |
| 23.08.2019          | 0.40                   | 0.80           | 0.27           |

Electrometric values of the coefficients **ρ** on average, by 40%, and in some cases by 70% reduced, compared to *ρ*. The quantitative distribution of the obtained qualitative characteristics of the impact hazard of the array is presented in table 4.

Table 4. Quantitative distribution of qualitative characteristics of rockburst hazard in the array Tashtagol Deposit for the period from 01.02.18 on 30.08.19 year.

| Data processing methods | *ρ* – electrometric coefficient determined according to the current instructions | **ρ** – electrometric coefficient determined with consideration of the geological structure of the electric profile |
|-------------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Quality indicators      | Possible manifestations of geodynamic phenomena                                  | Possible manifestations of geodynamic phenomena of class 3 and 5                                |
|                         | There is no possibility of geodynamic phenomena occurring in the rock mass      | Local stress concentration is carried out in the rock mass                                      |
|                         | Possible geodynamic phenomena of class 3 and 5                                  | Possible geodynamic phenomena occurring in the rock mass                                        |
|                         | Local stress concentration is carried out in the rock mass                      | Local stress concentration is carried out in the rock mass                                      |
|                         | Possible geodynamic phenomena of class 3 and 5                                  | Possible geodynamic phenomena of class 3 and 5                                                  |
| Quantity                | 35                                                                               | 19                                                                                |
|                         | 3                                                                                | 9                                                                                 |
|                         | 20                                                                               | 28                                                                               |

Electrometric coefficient **ρ** four times less often pointed to the absence of the possibility of geodynamic phenomena and nine times more often - on the possibility of occurrence of geodynamic phenomena above the third class. Figure 1 shows more clearly the comparison of average values of electrometric coefficients **ρ** for the horizon (-350). The graph clearly shows three periods characterized by a reduced (from October to December 2018) and increased geodynamic activity of the array (from February to September 2018 and from January to August 2019). In this case only the average values of the electrometric coefficients **ρ** in most cases they demonstrate compliance with registered geodynamic phenomena.

Fig. 1. Electrometric coefficients (*ρ* and **ρ**) and geodynamic phenomena for the period from 01.02.2018 to 30.08.2019.
This is also evidenced by data on average values $K_{ρ}^{**}$ for the horizon (-350) for recorded geodynamic phenomena shown in table 5.

Table 5. Correspondence of registered geodynamic phenomena to electrometric coefficients $K_{ρ}^{**}$

| % p. p. | Date of measurement | $K_{ρ}^{**}$ | The presence of geodynamic phenomena is higher third class | Correspondence of geodynamic phenomena to electrometric coefficients |
|---------|---------------------|-------------|--------------------------------------------------------|-------------------------------------------------|
| 1       | February 2018       | 0.7         | yes                                                   | Confirms                                       |
| 2       | March 2018          | 0.6         | no                                                    | Not confirmed                                  |
| 3       | April 2018          | 0.5         | yes                                                   | Confirms                                       |
| 4       | May 2018            | 0.4         | yes                                                   | Confirms                                       |
| 5       | June 2018           | 0.3         | yes                                                   | Confirms                                       |
| 6       | July 2018           | 1.4         | yes                                                   | Not confirmed                                  |
| 7       | August 2018         | 0.7         | yes                                                   | Confirms                                       |
| 8       | September 2018      | 0.6         | yes                                                   | Confirms                                       |
| 9       | October 2018        | 1.0         | yes                                                   | Not confirmed                                  |
| 10      | November 2018       | 0.9         | no                                                    | Confirms                                       |
| 11      | December 2018       | 1.9         | no                                                    | Confirms                                       |
| 12      | January 2019        | 0.4         | yes                                                   | Confirms                                       |
| 13      | February 2019       | 0.6         | yes                                                   | Confirms                                       |
| 14      | March 2019          | 0.6         | yes                                                   | Confirms                                       |
| 15      | April 2019          | 0.5         | no                                                    | Not confirmed                                  |
| 16      | May 2019            | 0.5         | yes                                                   | Confirms                                       |
| 17      | June 2019           | 0.4         | yes                                                   | Confirms                                       |
| 18      | July 2019           | 0.7         | yes                                                   | Confirms                                       |
| 19      | August 2019         | 0.4         | yes                                                   | Confirms                                       |

Table 5 shows that out of 19 measurements, the discrepancy between the electrometric coefficient $K_{ρ}^{**}$ and the registered geodynamic phenomena was found in four cases.

4 Conclusion

Thus, processing of measurement results taking into account the geological structure of electrophiles significantly approximates the electrometric forecast to the real assessment of the seismic events that occurred. The forecast efficiency increases to 80%.

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This is also evidenced by data on average values \( \rho K \) for the horizon (-350) for recorded geodynamic phenomena shown in Table 5.

Table 5. Correspondence of registered geodynamic phenomena to electrometric coefficients

| Date of measurement | \( \rho K \) | Presence of geodynamic phenomena | Correspondence |
|---------------------|--------------|----------------------------------|----------------|
| 1 February 2018     | 0.7          | yes                              | Confirms       |
| 2 March 2018        | 0.6          | no                               | Not confirmed  |
| 3 April 2018        | 0.5          | yes                              | Confirms       |
| 4 May 2018          | 0.4          | yes                              | Confirms       |
| 5 June 2018         | 0.3          | yes                              | Confirms       |
| 6 July 2018         | 1.4          | yes                              | Not confirmed  |
| 7 August 2018       | 0.7          | yes                              | Confirms       |
| 8 September 2018    | 0.6          | yes                              | Confirms       |
| 9 October 2018      | 1.0          | yes                              | Not confirmed  |
| 10 November 2018    | 0.9          | no                               | Confirms       |
| 11 December 2018    | 1.9          | no                               | Confirms       |
| 12 January 2019     | 0.4          | yes                              | Confirms       |
| 13 February 2019    | 0.6          | yes                              | Confirms       |
| 14 March 2019       | 0.6          | yes                              | Confirms       |
| 15 April 2019       | 0.5          | no                               | Not confirmed  |
| 16 May 2019         | 0.5          | yes                              | Confirms       |
| 17 June 2019        | 0.4          | yes                              | Confirms       |
| 18 July 2019        | 0.7          | yes                              | Confirms       |
| 19 August 2019      | 0.4          | yes                              | Confirms       |

Table 5 shows that out of 19 measurements, the discrepancy between the electrometric coefficient \( \rho K \) and the registered geodynamic phenomena was found in four cases.

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Thus, processing of measurement results taking into account the geological structure of electrophiles significantly approximates the electrometric forecast to the real assessment of the seismic events that occurred. The forecast efficiency increases to 80%.

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