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METHOD OF CALCULATION OF VOLUME AND DIRECTION OF GENERAL MINE NATURAL DRAFT WITH CONFIDENT PROBABILITY

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МЕТОДИКА РАСЧЕТА ВЕЛИЧИНЫ И НАПРАВЛЕНИЯ ОБЩЕРУДНИЧНОЙ ЕСТЕСТВЕННОЙ ТЯГИ С ЗАДАННОЙ ДОВЕРИТЕЛЬНОЙ ВЕРОЯТНОСТЬЮ

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In order to ensure safe working conditions of workers in underground mining, it is necessary to carry out ventilation of underground mining operations to reduce the concentration of harmful and dangerous gases in working areas. Volume air flow required for operation of a mine (shaft) is determined in accordance with a number of people being simultaneously in underground mining and based on intensity of the emission of toxic, combustible gases and dust, minimum air velocity and other factors relevant to a specific mining company. So, in order to maintain safe working conditions in the mine (shaft) fresh air must be supplied in required quantity determined by its needs.

A main fan is used to provide the mine with air. Through the supplying trunks, air enters underground mining and is removed by the ventilation shaft (suction method of ventilation).

Along with the main fan there is a general natural mine draft h_n, which occurs as a result of the difference in mean values of barometric pressure and air temperature. The magnitude and direction of the general natural draft h_n has an effect on the operation of the main fan. That increases if its direction of action coincides with the desired direction of air movement and decreases the performance of a main fan Q_F if the direction of its action is opposite to the direction of general mine draft.

The paper presents the method of calculating the value of general natural draft h_n taking into account the possible spread of its values due to the impact of the accidental circumstances, including those influencing the magnitude of the aerodynamic resistance of the mine.

The necessity of forming stochastic culture skills among students of technical universities is noted in studying methods of processing experimental data and constructing models of complex technical objects on their basis.

Ключевые слова:
безопасность подземных работ, общерудничная естественная тяга, стохастическое моделирование, стохастическая культура.

Для обеспечения безопасных условий труда горнорабочих на подземных горнодобывающих предприятиях необходимо осуществлять проветривание подземных горных выработок с целью снижения в рабочих зонах концентрации вредных и опасных газов. Объемный расход воздуха, необходимый для функционирования рудника (шахты), определяется в соответствии с числом людей, находящихся одновременно в подземных горных выработках, а также в зависимости от интенсивности выделения ядовитых, горючих газов и пыли, минимальной скорости движения воздуха и других факторов, актуальных для конкретного горнодобывающего предприятия. В связи с этим для поддержания безопасных условий труда в рудник (шахту) в необходимом количестве должен поступать свежий воздух, количество которого определяется его потребностями.

Для подачи воздуха в рудник используется главная вентиляторная установка (ГВУ), за счет работы которой воздух по воздухоподающим стволам поступает в подземные горные выработки и удаляется по вентиляционному стволу (всасывающий способ проветривания).

Наряду с работой ГВУ между шахтными стволами действует общерудничная естественная тяга $h_е$, возникающая вследствие разности средних значений барометрического давления и температуры воздуха. Величина и направление общерудничной естественной тяги $h_е$ оказывает влияние на работу ГВУ, увеличивая, если направление ее действия совпадает с требуемым направлением движения воздуха, либо снижая производительность $Q_В$ ГВУ, если направление ее действия противоположно направлению общерудничной естественной тяги.

В настоящей работе представлена методика расчета величины общерудничной естественной тяги $h_е$ с учетом возможного разброса ее значений из-за воздействия случайных обстоятельств, в том числе оказывающих влияние на величину аэродинамического сопротивления рудника.

Отмечена также необходимость формирования навыков стохастической культуры у студентов технических вузов при изучении методик обработки экспериментальных данных и построения моделей сложных технических объектов на их основе.

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Introduction

Calculation of the amount of air required to ventilate an underground mining company is currently determined by the face method. The method considers calculation of necessary fresh air volume flow for each face, mining area, service chamber, and then these volumes are summed up [1]. In this case, the volume of the required amount of air is calculated for the period of recovering of a certain section of a mine field. The volumetric flow rate of air supplied to a mine (shaft), established during calculations, can be modified by results of the airborne survey. Then, according to the "Safety Rules for Mining and Processing of Solid Minerals" [2], airborne depression should be conducted at least once every 3 years. In the rest of the time, there is no regulation of the volume flow of air supplied to an underground part of the company. Nevertheless, it is known that the volume is influenced by general natural draft which can vary considerably due to changes in the air environment in shafts.

Numerous studies are devoted to calculating the total natural draft [1, 3–14]. According to the currently used methods for calculating the general natural draft h_e, it is necessary to measure the parameters of the outside air, air in the shaft insets, air supplying tunnels, main fan units that are adjacent to a ventilation shaft, as well as in the channel of the main fan unit (MFU) and at some points in a underground part of a mining company. Measurements are usually required from several hours to several days [15]. During this time, the magnitude and direction of the general natural draft h_e can not change many times, and its impact on the volume of air supplied during this period will not be taken into account, which can lead to an unjustified increase in energy costs [16-18].

It is proposed in [19] to control the operation mode of the MFU using signals from a programmable logic controller where the absolute value of the general mine (shaft) natural draft h_e is calculated, depending on the current readings of the temperature and air pressure sensors located in shaft insets of air supplying shafts, main ventilation tunnels, MFU, and also recording the parameters at the surface. However, it is necessary to take into account that the system of ventilation of the mine (shaft) is inertial. After changing the operating mode of the MFU, the volumetric air flow changes in its channel and then in a ventilation shaft. Air distribution in an air supplying tunnel is changed after a certain period of time only.

Therefore, in order to control the operating mode of the MFU, it is necessary to take into account the change in current parameters that determine the value of a general mine (shaft) natural draft h_e. These changes depend on a variety of random factors. In order to evaluate them mathematical statistics is required [20-26]. In addition, initial experimental data, on the basis of which calculations are performed, contain inevitable errors. A method of obtaining them allows only a probabilistic estimate of the accuracy. Therefore, when building models based on them, it is necessary, in particular, to fulfill the requirements of checking their adequacy and limits of the confidence interval [27].

Description of the methodology for calculating the magnitude and direction of the general natural draft

The method proposed in works [28, 29] is used to determine the magnitude and direction of the natural draft h_e.

This method is designed for the experimental dependence of the statistical pressure h_B, developed by the MF, on its Q_B productivity, i.e. to search the corresponding regression equation.

Search for an appropriate regression equation should begin with a verification of existence of a correlation between the factor (square of the MFU performance Q_B^2) and response function (static pressure h_B).

Existence of a correlation relation is indicated by the difference between the correlation coefficient and zero. Its closeness to unity indicates that the connection is significant.

The regression equation is assumed to be linear with respect to coordinates (h_B; Q_B^2):

$$h_B = h_e + R_{mine} Q_B^2 \quad (1)$$

The required coefficients of the equation are R_{mine} – aerodynamic resistance of the mine (shaft), $(H \cdot s^2)/m^8$, and h_e – natural draft, Pa.

The coefficients h_e and R_{mine} are found from the system of equations based on the method of least squares [30]:

$$\begin{cases} \sum_{i=1}^{n} h_{B,i} - R_{mine} \sum_{i=1}^{n} Q_{B,i}^2 - h_e n = 0, \\ \sum_{i=1}^{n} h_{B,i} Q_{B,i}^2 - R_{mine} \sum_{i=1}^{n} Q_{B,i}^4 - h_e \sum_{i=1}^{n} Q_{B,i}^2 = 0 \end{cases} \quad (2)$$

and are calculated from by the formulas below:

$$R_{mine} = \frac{\overline{Q_B^2 h_B} - \overline{Q_B^2}\,\overline{h_B}}{\overline{Q_B^4} - \left(\overline{Q_B^2}\right)^2} \quad (3)$$

and

$$h_e = \overline{h_B} - R_{mine} \overline{Q_B^2}. \quad (4)$$

The bar over each of the variables means its average value, calculated from the experimental data.

The procedure for calculating the natural draft h_e from the experimental data for a given level of significance is given below. The methodology consists of several stages:

Stage I. Evaluation of significance of the linear correlation coefficient $r^{e.s}_{Q_B^2 h_B}$.

1. The correlation coefficient is estimated by the formula

$$r^{e.s}_{Q_B^2 h_B} = \frac{\overline{Q_B^2 h_B} - \overline{Q_B^2}\,\overline{h_B}}{\sqrt{\left(\left(\overline{Q_B^4}\right) - \left(\overline{Q_B^2}\right)^2\right)\left(\left(\overline{h_B^2}\right) - \left(\overline{h_B}\right)^2\right)}}. \quad (5)$$

The module of the obtained value is compared with unity as follows.

If $\left|r^{e.s}_{Q_B^2 h_B}\right| \approx 1$, then there is a linear correlation between Q_B^2 and h_B and it makes sense to calculate h_e.

If $\left|r^{e.s}_{Q_B^2 h_B}\right| \ll 1$, then a linear correlation between Q_B^2 and h_B there is no, and then it is necessary to look for the coefficient of determination $D_{Q_B^2 h_B} = \left(r^{e.s}_{Q_B^2 h_B}\right)^2$, showing how many percent of the regression equation explains the dependence of the response function on the factors under consideration.

2. We check the significance of the coefficient of linear correlation with help of the t-test of the Student.

For this purpose, the experimental value of the Student's t-test is determined for the correlation coefficient $r^{e.s}_{Q_B^2 h_B}$ by the formula

$$t^{e.s}_{r^{e.s}_{Q_B^2 h_B}} = \sqrt{\frac{(n-2)\left(r^{e.s}_{Q_B^2 h_B}\right)^2}{1 - \left(r^{e.s}_{Q_B^2 h_B}\right)^2}}. \quad (6)$$

Next, we set the significance level α and determine the critical value of the Student's t-test $t_\alpha^{crit} = t(\alpha;\ n - 2)$, which is found in statistical tables with the number of freedom $n - 2$, and where n is the volume of the sample set of experimental data.

If $t^{e.s}_{r^{e.s}_{Q_B^2 h_B}} < t_\alpha^{crit}$, then the coefficient of linear correlation $r^{e.s}_{Q_B^2 h_B}$ is not significant, and it should be taken equal to zero. That means that with probability $p = 1 - \alpha$ between the quantities Q_B^2 and h_B no linear link.

If $t^{e.s}_{r^{e.s}_{Q_B^2 h_B}} > t_\alpha^{crit}$, then the coefficient of linear correlation $r^{e.s}_{Q_B^2 h_B}$ is significant. This means that with probability $p = 1 - \alpha$ between the quantities Q_B^2 and h_B there is a linear relationship, therefore, one can proceed to a linear regression analysis.

Stage II. Calculating the coefficients h_e and R_{mine} the regression equation is performed by the formulas (3), (4).

If the value of the total natural draft h_e is positive, i.e. both ends of the confidence interval will lie in the positive area, it will prevent airing. Otherwise, when the values of the confidence interval are in the negative region, the total natural draft h_e will contribute to work of the MFU [28]. In order to assess the magnitude and direction of the overall natural draft h_e the next step is needed.

Stage III. Checking the significance of the calculated value h_e and estimation of the value of the corresponding confidence interval at a given significance level α.

The experimental value of the Student's test is calculated $t^{e.s}_{h_e}$ through a standard error m_{h_e} of a parameter h_e by the following formulas [20, 21, 29]:

$$t^{e.s}_{h_e} = \frac{h_e}{m_{h_e}},$$

$$m_{h_e} = \sqrt{\frac{\sum_{i=1}^{n}\left(h_{Bi} - R_{mine} Q_{Bi}^2 - h_e\right)^2}{(n-2)n} \frac{\sum_{i=1}^{n} Q_B^4}{\sum_{i=1}^{n}\left(Q_{Bi}^2 - \overline{Q_B^2}\right)^2}}. \quad (7)$$

Then two options are possible.

If $t_{h_e}^{e.s} < t_{\alpha}^{crit}$, then the natural draft h_e is not significant, and it is assumed to be zero.

If $t_{h_e}^{e.s} < t_{\alpha}^{crit}$, then the natural draft h_e is significant. Consequently, the value of natural draft h_e will lie in the confidence interval with probability $p = 1 - \alpha$, the boundaries of which are determined by the following formula:

$$h_e \in \left(h_e - m_{h_e} t_{\alpha}^{crit}(\alpha; n-2); h_e + m_{h_e} t_{\alpha}^{crit}(\alpha; n-2)\right). \quad (8)$$

The calculation procedure in three examples is illustrated based on results of measurements performed at one of the potash mines of the Perm Region.

During the experiment, efficiency of the MFU Q_B was changed by selectng the angle of installation of vanes of an axial fan guide. Experimental values were determined using a flowmeter located in a delivery (diffusive) channel [28, 31].

A change in the static pressure h_B, created by MFU, was determined with help of microbarometer devices located in delivery and suction (in a MFU channel) channels [28, 29].

Results of data processing using the calculation procedure described

Results of data processing for three pilot series A1, A2, A3.

<u>Series A1.</u> Below the are values of static pressure hB, created by a the MFU depending on its performance Q_B (series A1):

Q_B, m^3/s	219.9	230.1	264.3	282.1	299.5	312.6	330.5	367.1
h_B, Pa	1992.11	2241.62	2770.53	3340.14	3751.55	4126.36	4296.87	5449.18

Calculation results.

The coefficient of the linear correlation is evaluated for significance $r^{e.s}$.

The value of the correlation coefficient $r^{e.s}$, obtained from formula (5), $r^{e.s} = 0.99 \approx 1$. The proximity of the correlation coefficient to unity means that there is a linear correlation between Q_B^2 and h_B.

Substituting the data into formulas (3) and (4), we obtain the following values of natural draft and aerodynamic resistance of the mine: $h_e = 115.22$ Pa, $R_{mine} = 0.0396$ (N·s^2)/m^8.

The value of the natural draft was not found as a result of the processing of statistical data. Therefore, it is necessary to confirm the accuracy of the calculation (in this case the insignificance of the value of h_e) with help of the Student's t-criterion.

Using the formula (7), we find that the calculated value of the Student's coefficient for the natural draft is much less than its critical value: $t_{h_e}^{e.s} = 0.93 \ll 2.45 = t_{\alpha}^{crit} = t(0.05; 6)$, which confirms the insignificance of the coefficient of natural draft h_e. Therefore, we assume with a probability of 95 % that there was no natural draft at the time of measurements ($h_e = 0$). The limits of a confidence interval of the obtained value are estimated h_e by the formula (8). In this case, boundaries of the confidence interval have different signs, which confirms that the natural draft is close to zero:

$$h_e \in (115.22 - 123.98 \cdot 2.45; 115.22 + 123.98 \cdot 2.45) \equiv (-188.53; 418.98).$$

Note that if the volume n of a sample set of experimental data is small, the standard error is usually large, which leads to a stretching of the confidence interval and possible subsequent errors in conclusions.

The confidence interval allows determining the direction of a general natural mine draft. In particular, if both boundaries of the interval (8) have a negative sign "-", then a general natural draft value is negative. A positive sign "+" on both boundaries of the interval indicates that the value of thrust is positive. Considering this, if both boundaries (8) are negative, then the probability $p = 1 - \alpha$ directions of the action of the general natural draft and MFU will coincide, i.e. the draft will facilitate the natural ventilation of the mine (shaft). Positive boundaries of the interval (8) indicate that directions of the action of a natural draft and MFU will be opposite, i.e. a draft will prevent air from entering the mine.

Corresponding examples are given below.

<u>Series A2.</u> Below there are results of measurements of the static pressure h_B developed by MFU, depending on its Q_B performance, obtained in the second series of measurements:

Q_B, m^3/s	219.9	230.1	264.3	282.1	299.5	312.6	330.5	367.1
h_B, Pa	1193.52	1454.73	2121.54	2381.15	2792.56	3191.47	3771.87	4822.48

The coefficient of the linear correlation is evaluated for significance $r^{e.s}$:

Using the formula (5) the correlation coefficient value $r^{e.s} = 0.99 \approx 1$. The proximity of the correlation coefficient to unity means that there is a linear correlation between Q_B^2 and h_B.

Substituting the data from the table into formulas (3) and (4), we obtain the values of a natural draft and mine aerodynamic resistance: $h_e = -822.55$ Pa, $R_{mine} = 0.0415$ $(N \cdot s^2)/m^8$.

According to the formula (7), the calculated value of the Student's coefficient significantly exceeds its critical value for a natural draft value: $t_{h_e}^{e.s} = 8.85 \gg 2.45 = t_\alpha^{crit} = t(0.05; 6)$, which confirms the significance of the value of a natural draft h_e. The natural draft value is negative. Having the probability of 95 % its value lies in the confidence interval

$$h_e \in (-822.55 - 92.93 \cdot 2.45; -822.55 + 92.93 \cdot 2.45) \equiv (-1050.24; -594.87).$$

Thus, the calculation shows that with a probability of 95 % at the time of measurement, the value of natural draft he is negative. Than means the draft facilitates air delivery into the mine. In order to save energy, it is recommended to reduce the MFU performance by $\Delta h_e = 594.87$ Pa (down to the upper limit of the confidence interval). It is not recommended to use the average value of the confidence interval $h_e = 822.55$ Pa as a guide. The recommedation is based on two facts. Firstly, the value of a natural draft h_e with a probability of 0.95 can take any value within the limits of the confidence interval. Secondly, in case MFU performance is changed by $\Delta h_e = 822.55$ Pa, the volume of air entering the mine may not be sufficient enough to provide air supply conditions in the required volume. Moreover, it could be even worse scenario if MFU performance is attempted to reduce by $h_e = 1050.24$ Pa.

There are values of static pressure h_B in the Table below, created by the MFU depending on its capacity Q_B (series A3):

Q_B, m^3/s	219.9	230.1	264.3	282.1	299.5	312.6	330.5	367.1
h_B, Pa	2994.25	3151.88	4121.52	4511.23	4942.14	5128.58	5791.27	6611.91

The coefficient of the linear correlation is evaluated for significance $r^{e.s}$.

Using the formula (5) the correlation coefficient value $r^{e.s} = 0.954 \approx 1$. The proximity of the correlation coefficient to unity means that there is a linear correlation between Q_B^2 and h_B.

Substituting the data from the table into formulas (3) and (4), we obtain the values of a natural draft and mine aerodynamic resistance: $h_e = 1026.2$ Pa, $R_{mine} = 0.0426$ $(N \cdot s^2)/m^8$ (note that the value of natural draft is positive, $h_e > 0$).

According to the formula (7), the calculated value of the Student's coefficient significantly exceeds its critical value for a natural draft value: $t_{h_e}^{e.s} = 6.88 \gg 2.45 = t_\alpha^{crit} = t(0.05; 6)$, this confirms that the value of a natural draft h_e is significant. In the case considered both boundaries of the confidence interval for natural draft are h_e positive:

$$h_e \in (1026.2 - 149.12 \cdot 2.45; 1026.2 + 149.12 \cdot 2.45) \equiv (660.86; 1391.55).$$

Thus, at the time of measurement, a natural draft h_e interferes the air to enter the mine, which indicates the need to increase the performance of the MFU (at least by 1391.55 Pa to compensate the natural draft in the example considered).

We emphasize that in order to predict the behavior of complex technical systems, a researcher constantly has to take into account the influence of many factors and inaccuracy of the initial data. Therefore, obtained experimental results and models on their basis with a certain probability only can be trusted. Based on the circumstances mentioned above, the processing of experimental data requires a researcher to have a certain level of mastery of stochastic culture skills [27]. As a conclusion, it is necessary to develop the skills of stochastic culture in students of technical universities when studying the methods of processing experimental data and constructing models of complex technical objects on their basis.

Conclusions

The presented method for calculating the general natural mine draft allows detecting a draft and determine a direction with a given confidence probability. The calculations performed allow controlling the operation of a MFU, making corrections to ensure efficient ventilation. The calculation method developed can serve as a training model for training students in the Mining area who take the course of “Safety in mining operations” and “Automation of mining management”.

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