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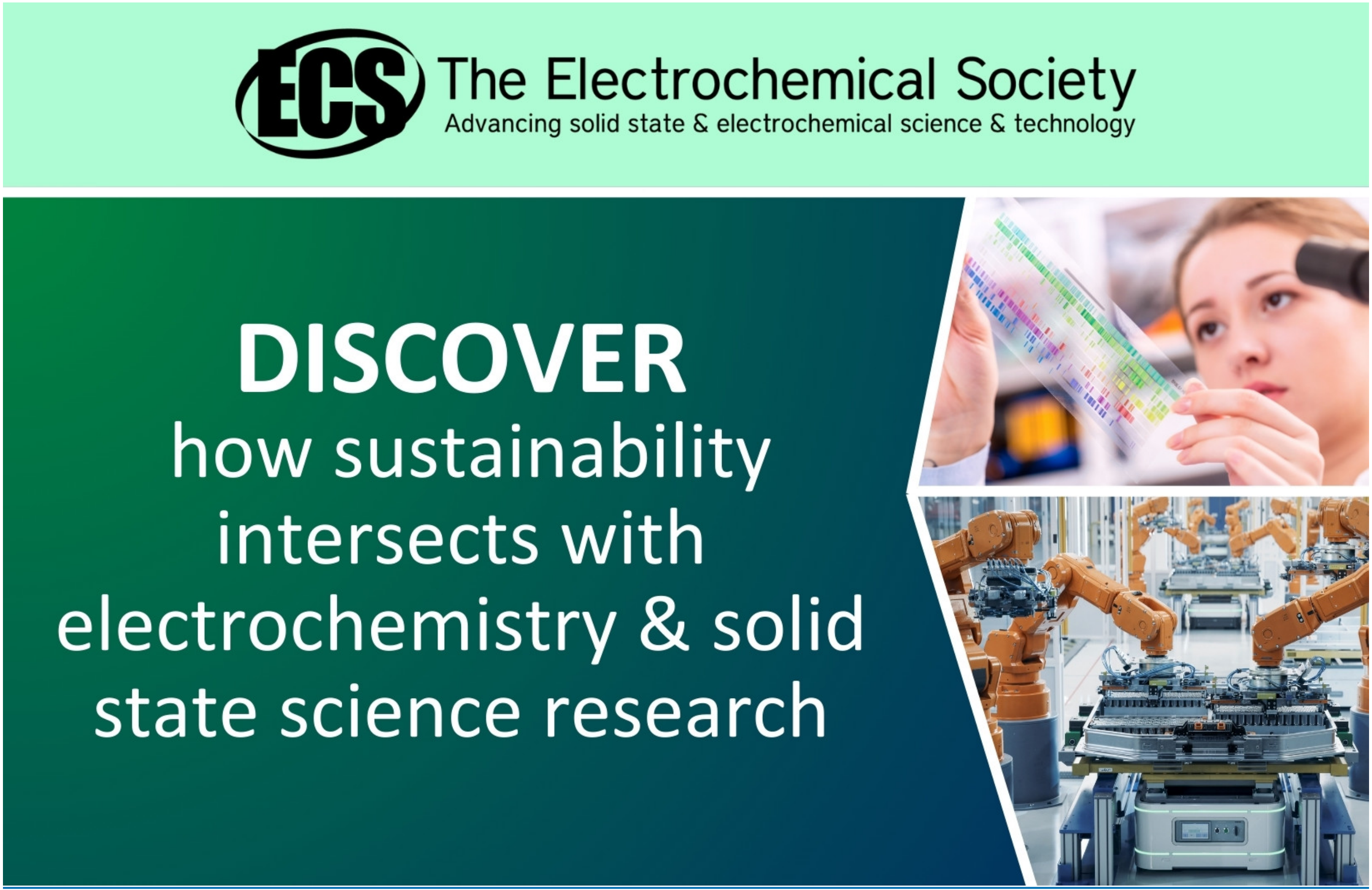

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Creation of the Information System Based on Experimental Data for Control of the MMF Operating Modes to Improve the Efficiency of Ventilation in Mines

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Abstract. The paper presents the results of two experiments conducted using the main mine fan in BKPRU-2 mine (PJSC Uralkali, Russia). The obtained data processing showed that a statistical verification of the measured data on their falsity and independence should be performed to effectively control the ventilation process. The mathematical dependences are provided for calculating the total natural draft during measurements, which significantly affects the ventilation process. This enables the control of ventilation in mines.

1. Introduction

In order to ensure safe operation of mines, fresh air must be supplied in the volume calculated for each individual underground mining enterprise using main mine fans (MMF). The parameters controlled during MMF operation are the MMF capacity Q_{MMF} and pressure h_{MMF}.

Ventilation requires from 30% to 50% of the total amount of electricity used in the underground mining enterprise. Therefore, in addition to the air supply provided in the required volume, this process should be performed without overstating the volume air flow supplied to the mine opening. To control MMF operation, automated air control systems are currently being introduced, in which data on the volume flow Q_{MMF} and pressure h_{MMF} of the air entering the mine are transferred from sensors to the control system.

The ventilation process is inertial, and MMF operation is affected by a significant number of factors. Thus, the required volume of air supply should be controlled in real time. At the same time, a change in the state of ambient air should be predicted. MMF operation is affected by the total natural draft, which can both increase and prevent the ventilation flow into the mine [1–4, etc.]. To develop the control system, it is required to create the information system that provides reliable, accurate and sufficient measurement results. At the same time, false data and data that do not satisfy the requirement for homogeneity of variance should be deleted from the continuously updated experimental database. The verification of homogeneity of variances in the sampling population of experimental data in the compared series and the absence of random and systematic errors will ensure the accuracy of further statistical processing and efficient control of ventilation.

2. Results and Discussion

In 2016 and 2017, a series of full-scale experiments was performed in BKPRU-2 mine (PJSC Uralkali, Russia) in order to develop a technique for database creation based on processing the data obtained in the MMF parameter measurements. During each of the two experiments (summer and winter), the MMF performance Q_{MMF} and corresponding values of static pressure h_{MMF} were measured at different rotational speeds of the fan runner (n_i).

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Each of the experiments included 9 series of measurements, and each of the series included 8–10 experimental values of the MMF performance Q_{MMF} and corresponding values of static pressure in the mine h_{MMF}.

The nine series of measurements in each of the two experiments (summer and winter) took about 20 minutes (two minutes per each series of measurements). About ten Q_{MMF} and h_{MMF} values were recorded. The experiment was performed within a short time period to avoid significant changes in the parameters of ambient air (temperature, atmospheric pressure, relative humidity, etc.), which have a considerable effect on the total natural draft h_e in the mine [1–6].

The experiments were carried out on July 6, 2016 and February 9, 2017, in summer and in winter, respectively. The ambient air parameters in summer were as follows: atmospheric pressure P_a =737.0 mm Hg (98258.6 Pa) and temperature t=21.8° C (294.95 K). In winter, the parameters were as follows: P_a = 779.8 mm Hg (103962.13Pa) and t = –2.1° C (271.05 K).

The results of the first and second experiments are summarized in Tables 1 and 2, respectively.

The experimental values of the MMF performance Q_{MMF} at different rotational speeds (n_i) of the runner are shown in Fig. 1. For example, the top curves in the graphs correspond to the first rows in Tables 1 and 2, which indicate the fan speed n=375 rpm.

Some measured values plotted in the graphs (Fig. 1) should be noticed.

The preliminary analysis of the obtained sampling populations of experimental values (Tables 1 and 2) indicates that the measurement results are apparently affected by random factors which cannot be allowed for during the experiments. Therefore, the creation of experimental databases should include a procedure of initial statistical verification of the measurement results for data randomness and independence to verify their reliability at a given level of significance α (with confidence coefficient p=1 − α).

Table 1. Measurement results (summer)

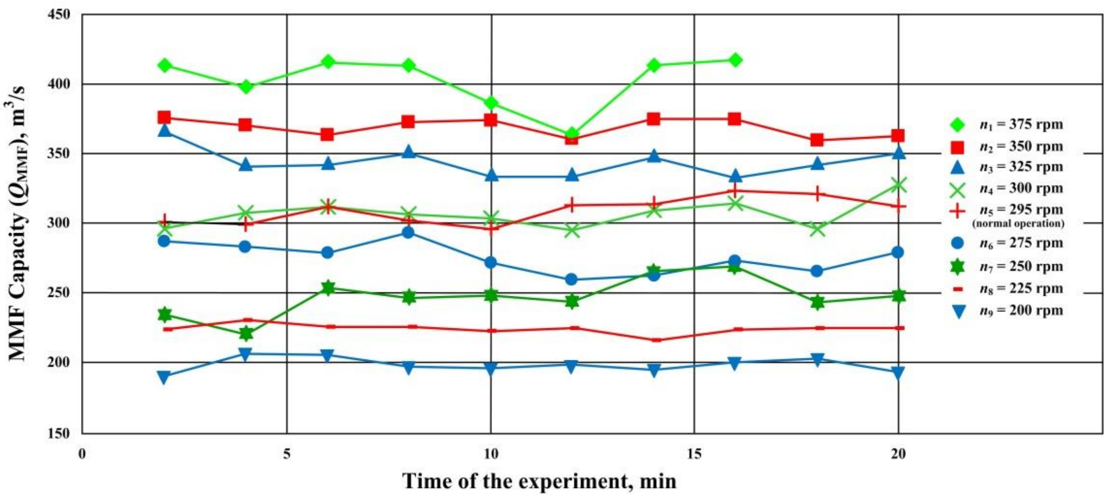
Series No.	Measurement results										
1	Q_{MMF}, m³/s	413	398	416	413	387	364	413	417	-	-
	h_{MMF}, Pa	2618.3	2618.3	2667.3	2628.1	2657.5	2637.9	2628.1	2618.3	-	-
2	Q_{MMF}, m³/s	376	371	363	373	374	360	375	375	359	362
	h_{MMF}, Pa	2304.5	2284.9	2314.3	2294.7	2343.7	2275.1	2324.1	2284.9	2265.3	2284.9
3	Q_{MMF}, m³/s	367	343	344	352	336	336	349	335	344	351
	h_{MMF}, Pa	2029.9	1980.9	2039.7	2039.7	2029.9	2039.7	2020.1	2000.5	2039.7	2010.3
4	Q_{MMF}, m³/s	296	307	312	306	303	295	310	315	296	328
	h_{MMF}, Pa	1745.5	1735.7	1774.9	1784.8	1745.5	1804.4	1755.3	1765.2	1774.9	1765.2
5	Q_{MMF}, m³/s	301	299	312	302	296	314	315	324	322	313
	h_{MMF}, Pa	1676.9	1676.9	1686.7	1676.9	1706.3	1686.7	1725.9	1725.9	1725.9	1725.9
6	Q_{MMF}, m³/s	287	283	279	293	272	260	263	273	266	279
	h_{MMF}, Pa	1480.8	1529.8	1500.4	1490.6	1500.4	1471	1490.6	1500.4	1500.4	1480.8
7	Q_{MMF}, m³/s	235	221	254	247	249	244	266	270	243	249
	h_{MMF}, Pa	1294.4	1314.1	1323.9	1274.8	1314.05	1304.3	1314.1	1294.4	1284.6	1284.6
8	Q_{MMF}, m³/s	224	231	226	226	224	225	217	224	225	225
	h_{MMF}, Pa	1078.7	1068.9	1049.3	1068.9	1068.9	1078.7	1068.9	1068.9	1059.1	1049.3
9	Q_{MMF}, m³/s	191	207	206	198	197	198	196	201	204	194
	h_{MMF}, Pa	882.6	872.8	863	882.6	873	863	863	853.2	853.2	863

Series: No. 1 – n_1 = 375 rpm; No. 2 – n_2 = 350 rpm; No. 3 – n_3 = 325 rpm; No. 4 – n_4 = 300 rpm; No. 5 (normal operation mode) – n_5 = 295 rpm; No. 6 – n_6 = 275 rpm; No. 7 – n_7 = 250 rpm; No. 8 – n_8 = 225 rpm; No. 9 – n_9 = 200 rpm.

Table 2. Measurement results (winter)

Series No.	Measurement results										
1	Q_{MMF}, m^3/s	410	416	404	399	415	411	416	412	391	378
	h_{MMF}, Pa	2696.83	2726.25	2706.64	2745.86	2667.41	2687.02	2736.06	2716.44	2726.25	2716.44
2	Q_{MMF}, m^3/s	375	382	362	360	383	385	395	394	396	346
	h_{MMF}, Pa	2412.44	2363.40	2412.44	2392.82	2422.24	2412.44	2402.63	2373.21	2363.40	2383.02
3	Q_{MMF}, m^3/s	356	369	356	366	353	341	331	332	355	355
	h_{MMF}, Pa	2088.82	2098.62	2118.24	2088.82	2118.24	2108.43	2069.20	2098.62	2059.40	2137.85
4	Q_{MMF}, m^3/s	330	343	336	348	318	329	302	311	315	320
	h_{MMF}, Pa	1794.62	1775.00	1863.26	1784.81	1824.04	1824.04	1794.62	1824.04	1745.58	1775.00
5	Q_{MMF}, m^3/s	320	320	320	327	315	306	321	324	331	335
	h_{MMF}, Pa	1735.78	1706.36	1706.36	1735.78	1686.74	1745.58	1765.20	1716.16	1725.97	1696.55
6	Q_{MMF}, m^3/s	302	290	297	294	297	286	294	308	297	301
	h_{MMF}, Pa	1529.84	1500.42	1529.84	1529.84	1510.22	1549.45	1529.84	1549.45	1539.64	1490.61
7	Q_{MMF}, m^3/s	264	265	267	279	284	258	282	273	263	260
	h_{MMF}, Pa	1235.64	1274.87	1265.06	1245.45	1274.87	1265.06	1255.25	1255.25	1265.06	1265.06
8	Q_{MMF}, m^3/s	241	241	234	238	247	236	240	249	249	249
	h_{MMF}, Pa	1029.70	1019.89	1039.51	1049.31	1029.70	1059.12	1049.31	1039.51	1029.70	1039.51
9	Q_{MMF}, m^3/s	224	226	218	225	220	222	214	215	224	220
	h_{MMF}, Pa	833.57	823.76	853.18	843.37	823.76	823.76	843.37	833.57	823.76	833.57

Series: No. 1 – n_1 = 375 rpm; No.2 – n_2 = 350 rpm; No. 3 – n_3 = 325 rpm; No. 4 – n_4 = 300 rpm; No. 5 (normal operation mode) – n_5 = 295 rpm; No. 6 – n_6 = 275 rpm; No.7 – n_7 = 250 rpm; No. 8 – n_8 = 225 rpm; No. 9 – n_9 = 200 rpm.



a)

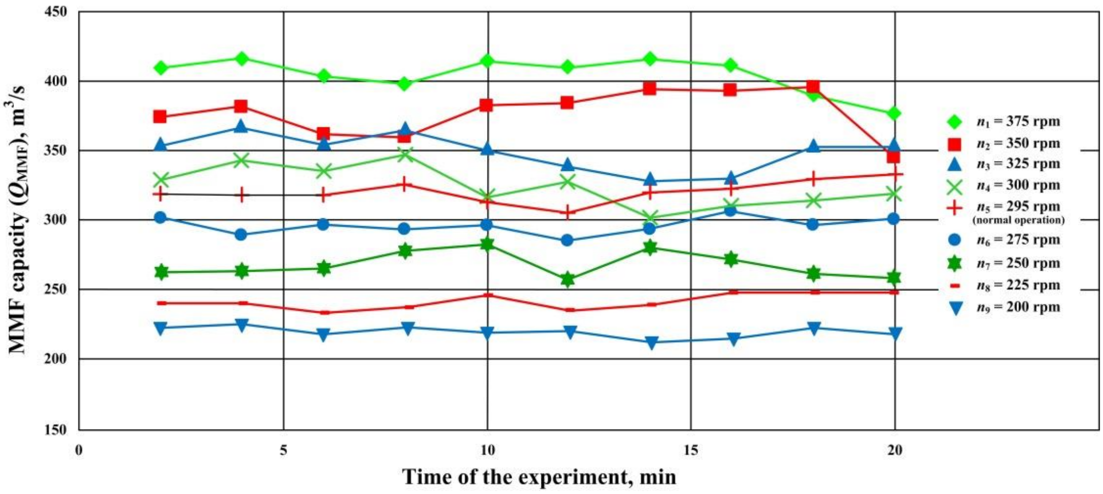


Figure 1. Q_{MMF} performance values at different rotational speeds of the fan runner: a – in summer; b – in winter

Since false data may cause wrong conclusions, primary processing of the experimental results starts with their exclusion in accordance with the requirements for mathematical statistics [7, 8].

Verification of data for validity is performed as follows.

In each series of measurements, data on the obtained sampling population should be arranged in ascending order: $x_{(1)} \leq x_{(2)} \leq \ldots \leq x_{(m)}$. Then, the extreme elements $x_{(1)} = x_{min}$ and $x_{(m)} = x_{max}$ should be determined. If x_{min} and x_{max} are significantly different, the competing hypotheses H_0 and H_1 should be statistically verified:

the null hypothesis H_0, when all the initial data are obtained under unchanged conditions and the sampling population can be assumed homogeneous;

the competing hypothesis H_1, when the value of one of the x_{min} and x_{max} results (or both) is obtained under considerably changed conditions (in this case, these values should be deleted from the sampling population as false).

Next, we need to calculate the experimental values of the Student's statistics τ_{exp}, that is, the characteristics τ_{exp}^{min} and τ_{exp}^{max} [7, 8]:

$$\tau_{exp}^{min} = \frac{|x_{min} - \bar{x}|}{S} \text{ and } \tau_{exp}^{max} = \frac{|x_{max} - \bar{x}|}{S}, \quad (1)$$

where $\bar{x}$ is the average value of experimental data, which is calculated from the *initial* sampling population of the volume m by the following formula:

$$\bar{x} = \bar{x}(m) = \frac{1}{m} \sum_{i=1}^{m} x_i . \quad (2)$$

S is the corrected (due to a small volume of the considered samples) sample mean squared deviation that shows distribution of the experimental values of the random variable X for the sampling mean $\bar{x}$:

$$S = S(m) = \sqrt{\frac{1}{m-1} \sum_{i=1}^{m} (x_i - \bar{x})^2} . \quad (3)$$

S is also calculated from the *initial* sampling population of experimental data. The τ_{exp}^{min} and τ_{exp}^{max} values show the deviation of the extreme value of the random variable (x_{min} or x_{max}) from its average value $\bar{x}$ with respect to the average distribution $\bar{S}$ of the random variable X in the sampling population.

Further, the experimental values of the Student's criterion τ_{exp}^{min} and τ_{exp}^{max} must be compared with the critical (theoretical) values $\tau_{cr}(\alpha,k)$, which can be found in statistical tables for a given number of degrees of freedom $k=m-1$ and a given value of the significance level α. In the information systems, critical values are recorded in the database.

The significance level α is the probability of rejecting the null hypothesis when it is true, which is known as type I error. The value α= 0.05 was adopted in the calculations below.

If the inequality $\tau_{exp} \leq \tau_{cr}$ (α, k) is satisfied, then H_0 hypothesis is not rejected. We assume that if the probability p=1−α, the test value x_{min} (or x_{max}) is not false and is left in the sample. Otherwise, the test value is deleted from the initial sampling population.

In this case, after excluding the next of the false experimental values, the characteristics $\bar{x}$ and S^2 must be recalculated for the remaining sampling. Thus, false data is deleted from each of the series separately.

The corrected variance S^2 is used to estimate the variance for the experimental data remaining in the test series. Thus, each of the experimental data series is processed in succession.

Next, we compare the variances of different series. The variances must be homogeneous [7, 8]. The homogeneity of variances indicates that the data are obtained with equal accuracy.

The homogeneity of variances in the entire sampling population of experimental data in the compared series is a prerequisite for creating the information system database. Only in this case it can be used to develop the information system for practical purposes, including the automated ventilation process. The comparison can be performed, for example, by pairwise comparing the variances of series.

As a result, the series with homogeneous variances remain in the resulting population, which ensure the reliability of subsequent calculations and analysis of the results for a given α.

The homogeneity of variances is estimated using the Fisher's criterion F. The experimental value of the Fisher's criterion F^{exp} is calculated by the formula [7, 8]:

$$F^{exp} = \frac{S_1^2}{S_2^2}, \tag{4}$$

where the numerator shows the largest variance.

The experimental value of the Fisher's criterion must be compared with the critical value $F_{cr}(\alpha;k_1;k_2)$, which can be found in statistical tables for a given value of the significance level α and given values of the numbers of degrees of freedom k_1, k_2 [7, 8].

If $F^{exp} > F_{cr}(\alpha;k_1;k_2)$, then the variances in the compared series should be assumed inhomogeneous (different). This means that the measurements are performed with different degrees of accuracy, and they cannot be included in a single database. Therefore, a series with a variance different from that of other series in data processing must be deleted from the experimental database, and the corresponding experiments should be repeated if required.

The average values of the productivity $\overline{Q_{MMF}}$ and static pressure $\overline{h_{MMF}}$ should be calculated in each of the remaining series with homogeneous variances.

Only after calculating the $\overline{Q_{MMF}}$ and $\overline{h_{MMF}}$ average values, the correlation-regression analysis can be performed.

The total natural draft h_e, which significantly affects the MMF operating mode, can be calculated from equation [9]:

$$\overline{h}_e = \overline{h_{MMF}} - R_{mine}\,\overline{Q_{MMF}^2}, \tag{5}$$

where R_{mine} is the aerodynamic resistance of the mine, H·s2/m8, which can be determined from equation [9]:

$$R_{mine} = \frac{\overline{Q_{MMF}^2 \cdot h_{MMF}} - \overline{Q_{MMF}^2} \cdot \overline{h_{MMF}}}{\overline{Q_{MMF}^4} - \left(\overline{Q_{MMF}^2}\right)^2}. \tag{6}$$

The total natural draft h_e obtained in the experimental data processing will enable determining the degree of its effect on the ventilation process. The positive total natural draft h_e, which improves MMF operation, can reduce the fan performance and thereby increase the energy efficiency of ventilation. In case of negative total natural draft, MMF performance should be increased by the draft value to ensure ventilation in the safe mode, but with minimal energy consumption.

3. Conclusion

Table 3 summarizes the results of the primary experimental data processing for two experiments.

Due to the deletion of inhomogeneous variances, the average values of the total natural draft h_e increase. The limits of the confidence interval for natural draft in the summer experiment are positive, which indicates the effect of negative natural draft [10]. In the winter experiment, the lower limit of the interval h_e is negative, whereas its upper limit is positive. Due to the fact that the upper limit of the interval h_e is of greater significance, with the probability of 95% in the mine, negative total natural draft takes place in the winter experiment, but its value is much smaller than that in the summer experiment.

The summer and winter experiments can be performed with different accuracy, which is unacceptable for statistical analysis, that is, the variances of the two compared sampling populations should be homogeneous.

Thus, the experiments have shown that a significant number of different factors that affect the fan performance, total natural draft that varies within a wide range (Table 3) in particular, must be taken into account to efficiently control the MMF operating modes. Therefore, it is impossible to consider the results of measurements only. Real time deletion of false data by statistical methods, timely averaging of the measured Q_{MMF} and h_{MMF} values, that is, creation of the information system based on the data obtained, are crucial for efficient control of ventilation in the mine with regard to disturbing effects.

Table 3. The results of the primary experimental data processing for two experiments.

	R_{mine}	h_e	H_{lower}	H_{upper}
No processing (Regression for the entire population)				
Summer	0.0136508	414.972	359.581	470.362
Winter	0.015555598	138.668	65.826	211.510
No processing (Regression for the average values of the series)				
Summer	0.014036824	380.610	276.947	484.273
Winter	0.016193351	75.989	19.611	132.367
After deletion of false data only				
Summer	0.013735125	406.121	284.478	527.765
Winter	0.016193351	75.989	19.611	132.367
After deletion of false data and inhomogeneous variances				
Summer	0.012670162	539.199	351.489	726.908
Winter	0.015800267	123.242	-57.207	303.692

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