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INFLUENCE OF APPLYING ADDITIONAL FORCING FANS FOR THE AIR DISTRIBUTION IN VENTILATION NETWORK

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Abstract:
Mining progress in underground mines cause the ongoing movement of working areas. Consequently, it becomes necessary to adapt the ventilation network of a mine to direct airflow into newly-opened districts. For economic reasons, opening new fields is often achieved via underground workings. Length of primary intake and return routes increases and also increases the total resistance of a complex ventilation network. The development of a subsurface structure can make it necessary to change the air distribution in a ventilation network. Increasing airflow into newly-opened districts is necessary. In mines where extraction does not entail gas-related hazards, there is possibility of implementing a push-pull ventilation system in order to supplement airflows to newly developed mining fields. This is achieved by installing subsurface fan stations with forcing fans at the bottom of downcast shaft. In push-pull systems with multiple main fans, it is vital to select forcing fans with characteristic curves matching those of the existing exhaust fans to prevent undesirable mutual interaction. In complex ventilation networks it is necessary to calculate distribution of airflow (especially in networks with a large number of installed fans). In the article the influence of applying additional forcing fans for the air distribution in ventilation network for underground mine were considered. There are also analysed the extent of overpressure caused by the additional forcing fan in branches of the ventilation network (the operating range of additional forcing fan). Possibilities of increasing airflow rate in working areas were conducted.

Key words: *underground mine ventilation, ventilation network, air distribution in ventilation network, intake air flow, main fans, additional forcing fans*

INTRODUCTION

Mining progress and the movement of working areas frequently cause the length of primary intake and return airways to increase, which in turn increases the total resistance of a complex ventilation network. Mines also opening new mining fields. For economic reasons, opening new fields is often achieved via underground workings. If new fields are accessed via shafts, usually downcast shafts are used for this purpose for technological reasons. In recent years also some mining areas were connected. As a result, the ventilation network becomes increasingly complex. Length of primary intake and return routes increases and also increases the total resistance of a complex ventilation network.

In Polish coal mines exhausting ventilation system were used and main fan stations were sited majority on surface. Fresh air enters the system through one or more downcast shafts. Next the air flows along intake airways to the working areas. Air passes back through the system along return airways. The return air passes back to the surface via one or more upcast shafts.

In mines with more than one upcast shaft main fans can interrupt in various places in mine ventilation network. Booster fans are often employed in mines, primarily as means of controlling airflow distribution in the ventilation network by overcoming the pressure drop. However, their placement and available capacity does not increase the total amount of air carried into the system.

The extension of a mine may require changing the distribution of air in a ventilation network. The reason of this changes is increasing the volumetric airflow in new fields. In mines where extraction does not entail gas-related hazards, there is possibility of implementing a push-pull ventilation system in order to supplement airflows to newly developed mining fields. In complicated ventilation networks there are usually more downcast shafts than upcast shafts. In mines extracting non-flammable minerals there is a possibility of connecting the main fans to the downcast shaft in order to provide a forcing air into shaft to increase air quantity in the network.

In complex ventilation networks it is necessary to calculate distribution of airflow (especially in networks with a large number of installed fans). In the case of ventilation networks with a single downcast shaft and a single upcast shaft, the selection of a forcing fan to be used in the network is relatively simple. In real, extended ventilation networks, the task of selecting an appropriate forcing fan is much more complex.

In the article the analysis of influence of applying additional forcing fans for the air distribution in ventilation network were conducted.

Results of each calculations in the article were achieved using Hardy Cross method of solving ventilation networks [3].

SUBSURFACE VENTILATION SYSTEMS

Exhausting ventilation system is the most popular in underground mines. Main fan station are located on the surface. The extension and development of a mine may demand increasing the volumetric airflow in new fields. In mines where extraction does not entail gas-related hazards, there is possibility of implementing a push-pull ventilation system in order to supplement airflows to newly developed mining fields. This is achieved by installing subsurface fan stations with forcing fans at the bottom of downcast shaft. Figure 1 (a-d) presents distribution of pressure drop in ventilation network for different localisation of the main fan in the system; a) exhausting ventilation system, b) forcing ventilation system with one fan, c) push-pull system with two fans.

In push-pull systems with multiple main fans, it is vital to select forcing fans with characteristic curves matching those of the existing exhaust fans to prevent undesirable mutual interaction. Figure 2 presents correct (a, b) and incorrect (c) distribution of pressure drop in ventilation network for push-pull system with two fans.

Aerodynamic potential of ventilating air with reference to unit mass of dry air, which has been defined by H. Byston [2] is a factor which allows evaluating influence of fan's operation on individual places in ventilation network.

It is possible to divide a network into subnets of individual main-fans on the based on the value of aerodynamic potential. Subnet of the fan is a set of airways (branches) under the influence of overpressure of the fan. Sometimes ventilation networks can make a clear distinction between subnets (the so-called division of network into groups, according to work [9]).

Most, however, in the ventilation system are branches, which can not be clearly assigned to a particular subnet, because they are under the influence of a greater number of fans. This occurs in complex networks, with more fans. These fans are interacting in a suction way on branches of the network make some of them are under the joint influence of the fans, and part of them are directly related to the subnet of a fan [1, 5, 7, 8]. For security cooperation of fans, it seeks to value of the potential in the last separating node on the subnets the lowest [2, 5].

In the next part of the article were taken the analysis of installing subsurface fan stations with forcing fans at the bottom of downcast shaft. The reason of installing additional forcing fan is increasing the volumetric airflow in new fields (in particular mining districts). Installing additional forcing fan have also influence on the distribution of pressure drop in ventilation network.

In complex ventilation networks it is necessary to calculate distribution of airflow (especially in networks with a large number of installed fans) [4, 5]. In order to perform the calculations, one can use a model of network structure in the form of canonical diagrams.

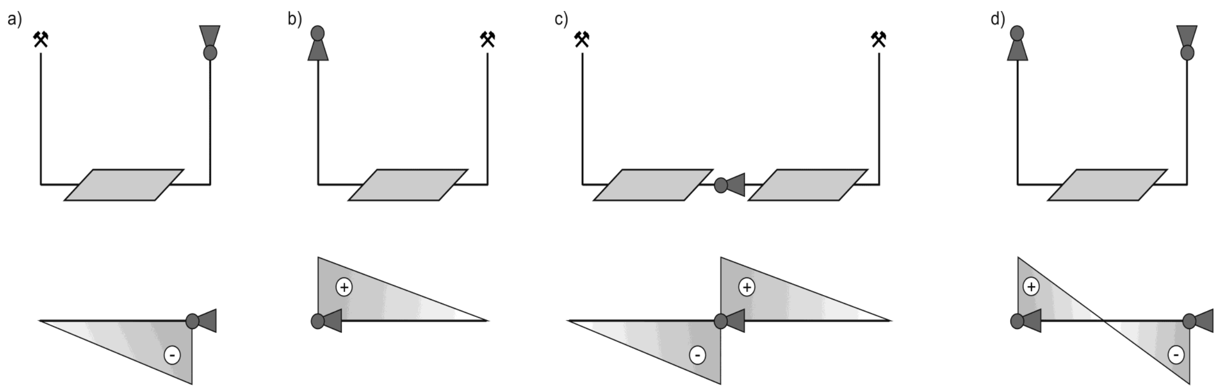

Fig. 1 Correct distribution of pressure drop in ventilation network for different localisation of the main fan: a) exhausting ventilation system, b) forcing ventilation system with one fan, c) push-pull system with two fans

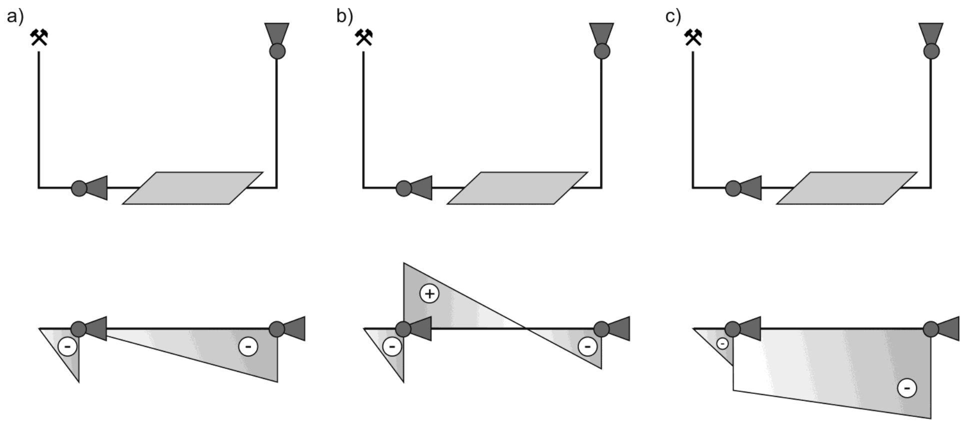

Fig. 2 Distribution of pressure drop in ventilation network for push-pull system with two fans: a), b) correct distribution of pressure drop, c) incorrect distribution of pressure drop

In these diagrams, ventilation districts consisting of many branches with serial, parallel and diagonal connections to one another can be represented by a single branch with an equivalent resistance [1, 6]. Methods of complex ventilation network analysis can be employed for the calculations. Calculations in the article were developed using VENTGRAPH software. In order to solve calculations in the code of this software, the Hardy Cross method was employed.

STRUCTURE OF THE VENTILATION SYSTEM

To achieve data for the analysis of airflow distribution in ventilation network the measurements in real-life mine were conducted. Measurements have taken place in winter season. According to the measurements the aerodynamic potential in branches (resistances of branches) were calculated. Measurements included:

- barometric pressure in ventilation network nodes (junctions),
- dry-bulb globe air temperature and wet-bulb globe air temperature in the beginning and in the end of excavations,
- air velocity in excavations.

Because of changing air parameters in the surface there were also measured barometric pressure, and temperatures (dry-bulb globe and wet-bulb globe temperature) in the surface next to the downcast shaft.

Barometric pressure were measured with accuracy ±0,1 hPa. Dry-bulb and wet-bulb globe air temperature were measured using Assmann psychrometer. Air velocity were measured using anemometers with measuring range 0,2 to 15,0 m/s. To measure of the average air velocity in cross-section area, traverse method was applied. There were also measured dimensions of cross-section area in each places to calculate volumetric airflow.

According to measured values simplified model of the ventilation network were developed. In order to assess the correctness of the designated input has been made to verify:

- structure of the network,
- calculated resistance of branches.

Validate the structure of the network was made at the stage of the establishment of a set "edtext", mainly by controlling the incidence of branches and network nodes. The correctness of the other data was checked by calculating the air distribution program "gras" and comparing the calculation results with the data input.

Analysis of the calculation results of the air distribution in the network model revealed that the input data has been set correctly. Direction of air flow in the all branches of the network are in accordance with the detected time measurements and the calculated flow rates of air are close to the measured in the ventilation system.

Resistance of individual airways was determined on the basis of measurements carried out on the underground excavations. Measurements of thermodynamic parameters of air in the excavations and the barometric pressure at cross roadways have been taken. Resistance of branches was calculated on the basis of the designated pressure drops. The calculation also takes into account changes in air density in the branches of network.

AIRFLOW DISTRIBUTION IN THE VENTILATION NETWORK (STARTING POINT)

Figure 3 presents a simplified layout of the ventilation network for real-life underground mine. The ventilation network can be classified as a highly complex one [9, 10].

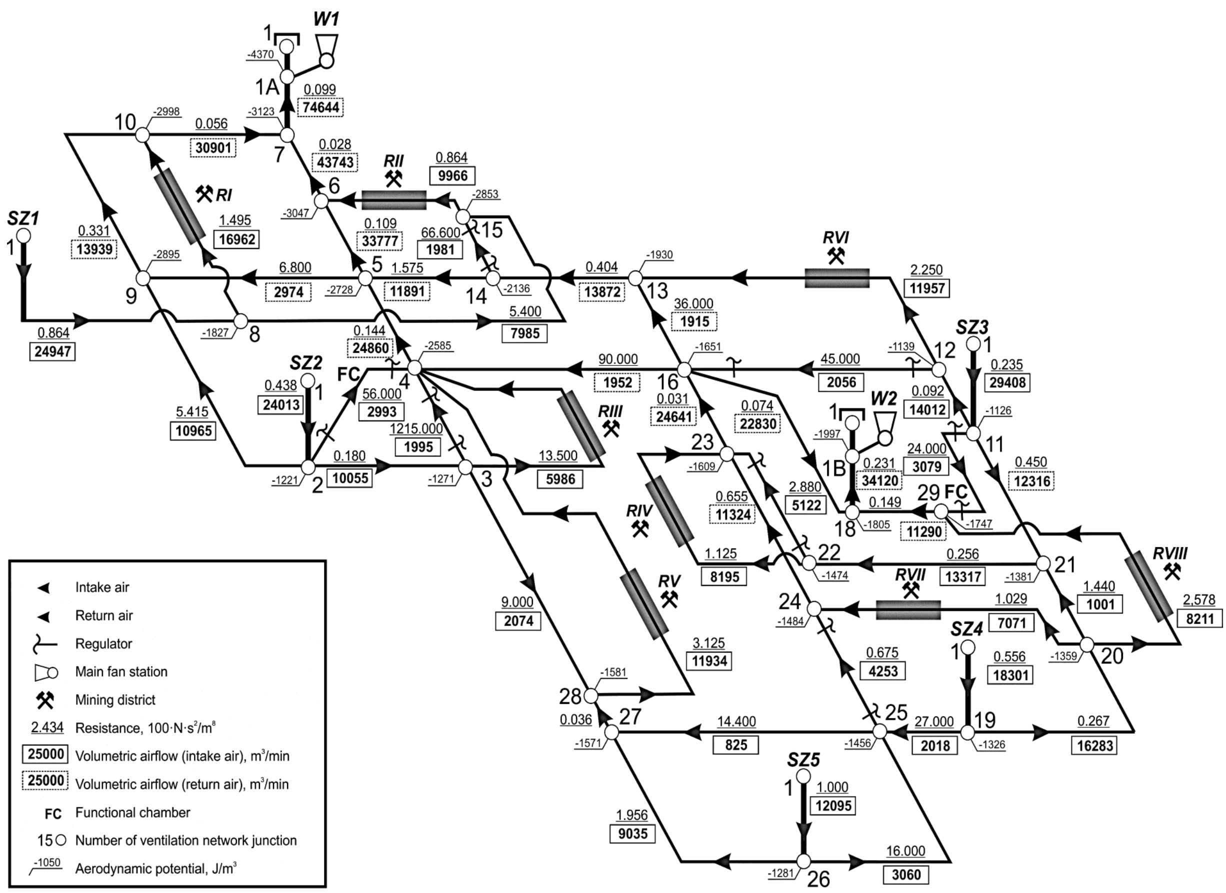

Fig. 3 Simplified layout of the ventilation network for real-life mine (starting point)

Air is supplied to subsurface excavations via five downcast shafts and returned via two upcast shafts with stations of main fans on the surface. The network covers eight mining districts and functional chambers indicated in Figure 3. The figure also shows airways with regulators. The resistance values of individual branches were calculated on the basis of measurements conducted in primary main airways (resistance values based on the measured values of airflow, barometric pressure and bulb temperatures). Because of high complication of real-life mine ventilation networks layout of the mine were simplified. Airflow rate in each branches (Figure 3) are the result of calculation taking into account conducted measurements. Simplified layout consists of 57 branches and 33 nodes, forming 25 independent ventilation meshes. For the ventilation system under analysis, it has been proposed to connect a main fan station to the bottom of one of the downcast shaft (Fig. 3) in order to increase airflow through this shaft.

At shaft W1, a main fan station consist fans working in parallel; its combined characteristic curve is described by the following equation:

$$\Delta p = -0.0058 \cdot Q^2 + 9.12 \cdot Q + 2419 \qquad (1)$$

At shaft W2, the combined characteristic curve of the working fans is described by the following equation:

$$\Delta p = -0.0786 \cdot Q^2 + 68.48 \cdot Q - 10617 \qquad (2)$$

where:
Q – volumetric airflow rate, m^3/s.

The results of calculations airflow distribution in ventilation network for starting point are presented in Table 1. The highest volumetric air flow rate is supplied to the mine via shafts SZ1, SZ2 and SZ3.

Analysed ventilation network covers eight mining districts. The results of the calculations of volumetric air flow rate in mining districts and aerodynamic potentials are presented in Table 2. The airflow rate supplied to the mining district achieved almost 74% of the total air supplied to the mine. Underground, near the upcast shafts there were also located functional chamber. The airflow rate supplied to the functional chamber achieved almost 5.5% of the total air supplied to the mine.

The results of the calculations of volumetric air flow rate, total pressure and equivalent orifice of the mine for main fan station in starting point are presented in Table 3. Higher volumetric airflow and higher total pressure are reached fans working on shaft W1.

Table 1
The results of the calculations of volumetric air flow rate in downcast shafts (starting point)

No.	**Shaft**	**Intake air flow**	**Percentage of the total intake air flow**
		m^3/min	%
1	SZ1	24947	22.9
2	SZ2	24013	22.1
3	SZ3	29408	27.0
4	SZ4	18301	16.8
5	SZ5	12095	11.2
Total intake air flow		**108764**	**100.0**

Table 2
The results of the calculations of volumetric air flow rate and pressure drop in mining districts (starting point)

No.	**Mining district**	**Volumetic air flow**	**Percentage of the total intake air flow**	**Aerodynamic potential**	
				Inlet to the mining district	**Outlet from the mining district**
		m^3/min	**%**	**J/m^3**	**J/m^3**
1	RI	16962	15.6	-1494	-2689
2	RII	9966	9.2	-2450	-2688
3	RIII	5986	5.5	-752	-2095
4	RIV	8195	7.5	-880	-1090
5	RV	11934	11.0	-860	-2095
6	RVI	11957	11.0	-615	-1508
7	RVII	7071	6.5	-714	-856
8	RVIII	8211	7.5	-714	-1197
	Total	**80282**	**73.8**	**-**	**-**

Table 3
The results of the calculations of volumetric air flow rate and pressure drop in mining districts (starting point)

Shaft	**Volumetric airflow rate**			**Total pressure**		**Equivalent orifice of the mine**	
	In shaft	**Shaft leakages**	**Fans**	**Across the mine**	**Across the fans**	**Across the mine**	**Across the fans**
		m^3/min		**Pa**		**m^2**	
W1	74644	3024	77668	4369	4470	22.17	23.07
W2	34120	2050	36170	1996	2102	14.78	15.67
Total	**108764**	**5074**	**113838**	**-**	**-**	**-**	**-**

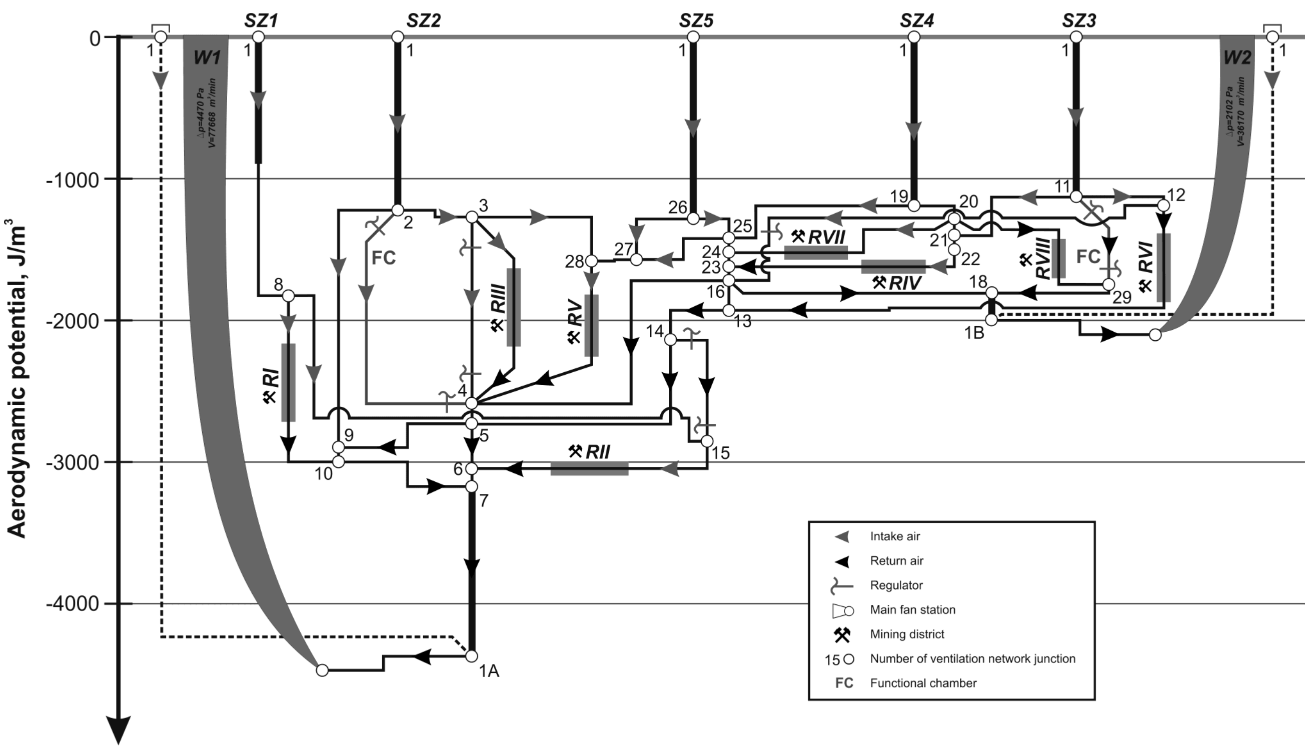

Fig. 4 Graph of aerodynamic potential in nodes of ventilation network (starting point)

In Figure 4 graph represent the aerodynamic potential in nodes of ventilation network for starting point are presented.

For presented mine considerations with regard to introducing a forcing fan at the upcast shaft were taken. Forcing fans are sited underground near the shaft SZ4. The aim of installing forcing fans in the primary ventilation system of a multiple-fan mine is to step up the primary ventilation capacity (especially in mining districts located near the shaft with additional forcing fan).

AIRFLOW DISTRIBUTION IN THE VENTILATION NETWORK (WITH ADDITIONAL FORCING FAN)

For the ventilation network of the mine were made calculations of airflow distribution after installing additional forcing fan at the bottom of downcast shaft SZ4. The following approximation equations for the characteristic curve of the forcing fan were applied for the calculations:

$$\Delta p = -0.01 \cdot Q^2 - 0.55 \cdot Q + 5000 \qquad (3)$$

Figure 5 presents a simplified layout of the ventilation network with installing additional forcing fan.

On this figure are presented the results of the calculations of volumetric airflow rate in each branches.

In table 4 the results of the calculations of volumetric airflow rate in downcast shafts for variant with additional forcing fan are presented. Calculations shows that the distribution of air in ventilation network were changed. For the variant with additional forcing fan the highest airflow rate were supplied to the mine through the shaft SZ4 and achieved more than 34% of the total air supplied to the mine. For other downcast shafts the airflow rate were reduced. The reduction is dependent of the localisation of that shafts in mining area. Bigger reduction of airflow rate occurred in shaft located nearest the shaft with additional forcing fan.

The results of the calculations of volumetric air flow rate in mining districts and values of aerodynamic potential in nodes for variant with additional forcing fan are presented in Table 5. An analysis of the obtained results reveals that installing a forcing fan in the upcast shaft SZ4 causes a slight increase in the total airflow in the ventilation network of the mine. The value of the increase obtained were 2.5% respectively compared with the starting point. However, the distribution of air in ventilation network was changed significantly. The airflow rate supplied to the mining district achieved almost 80% of the total air supplied to the mine. Underground, near the downcast shafts there were also located functional chamber. The airflow rate supplied to the functional chamber achieved about 4.5% of the total air supplied to the mine. The reduction depends on the reducing the airflow supplied to the mine by this shafts.

The results of the calculations of volumetric air flow rate, total pressure and equivalent orifice of the mine for main fan station in variant with additional forcing fan are presented in Table 6. Higher volumetric airflow and higher total pressure reached by fans working on shaft W1, similarly like in starting point. The parameters of fan working on shaft SZ4 are changed insignificantly in comparison to starting point. Total pressure reached by fans working on shaft W2 is lower than in the starting point (the total pressure is lower about 550 Pa than in starting point). In this variant in the ventilation network also working additional forcing fan. Conducted calculation shows that additional forcing fans reaches 38300 m^3/min airflow and about 3800 Pa of total fan pressure.

In Figure 5 are presented simplified scheme of the ventilation network, showing the extent of overpressure caused by the additional forcing fan in branches of the network and indicating the branches in which the direction of airflow was reversed.

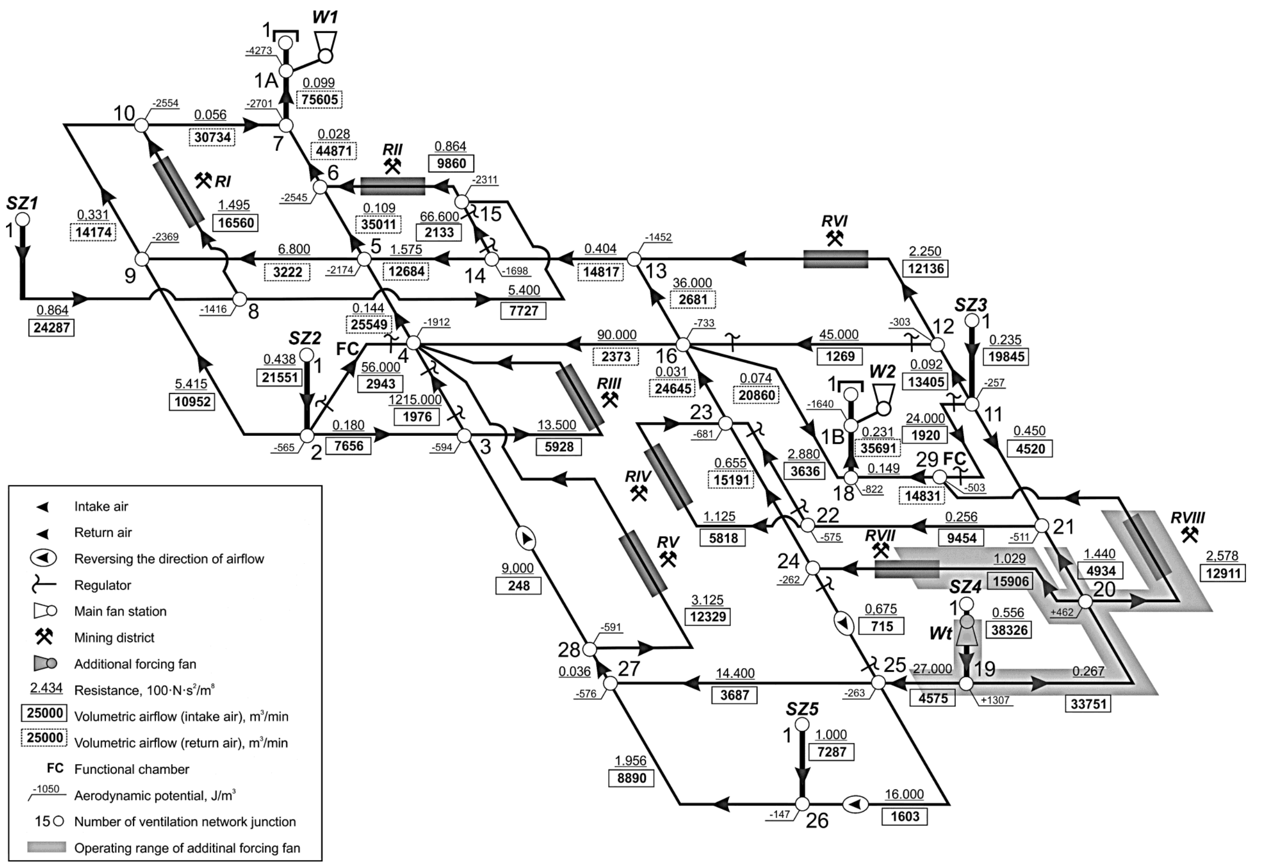

Fig. 5 Simplified layout of the ventilation network for real-life mine (variant with additional forcing fan)

Table 4
The results of the calculations of volumetric airflow rate in downcast shafts (with additional forcing fan)

No.	Shaft	Intake airflow	Percentage of the total intake airflow
		m^3/min	%
1	SZ1	24287	21.8
2	SZ2	21551	19.4
3	SZ3	19845	17.8
4	SZ4	38326	34.4
5	SZ5	7287	6.6
Total intake air flow		**111296**	**100.0**

Table 5
The results of the calculations of volumetric airflow rate and pressure drop in mining districts (variant with additional forcing fan)

No.	Mining district	Volumetic air flow	Percentage of the total intake air flow	Aerodynamic potential	
				Inlet to the mining district	Outlet from the mining district
		m^3/min	%	J/m^3	
1	RI	16560	14.9	-1416	-2554
2	RII	6860	6.2	-2311	-2545
3	RIII	5928	5.3	-594	-1912
4	RIV	5818	5.2	-575	-681
5	RV	12329	11.1	-591	-1912
6	RVI	12136	10.9	-303	-1452
7	RVII	15906	14.3	462	-503
8	RVIII	12911	11.6	462	-262
	Total	**88448**	**79.5**	**-**	**-**

Table 6
The results of the calculations of volumetric airflow rate, total pressure and equivalent orifice of the mine for main fan station (variant with additional forcing fan)

Shaft	**Volumetric airflow rate**			**Total pressure**		**equivalent orifice of the mine**	
	In shaft	**Shaft leakages**	**Fans**	**Across the mine**	**Across the fans**	**Across the mine**	**Across the fans**
		m³/min		**Pa**		**m²**	
W1	75605	2991	78596	4273	4376	22.70	23.60
W2	35691	1724	37415	1640	1524	18.16	19.03
Total	**108764**	**5074**	**113838**	**-**	**-**	**-**	**-**

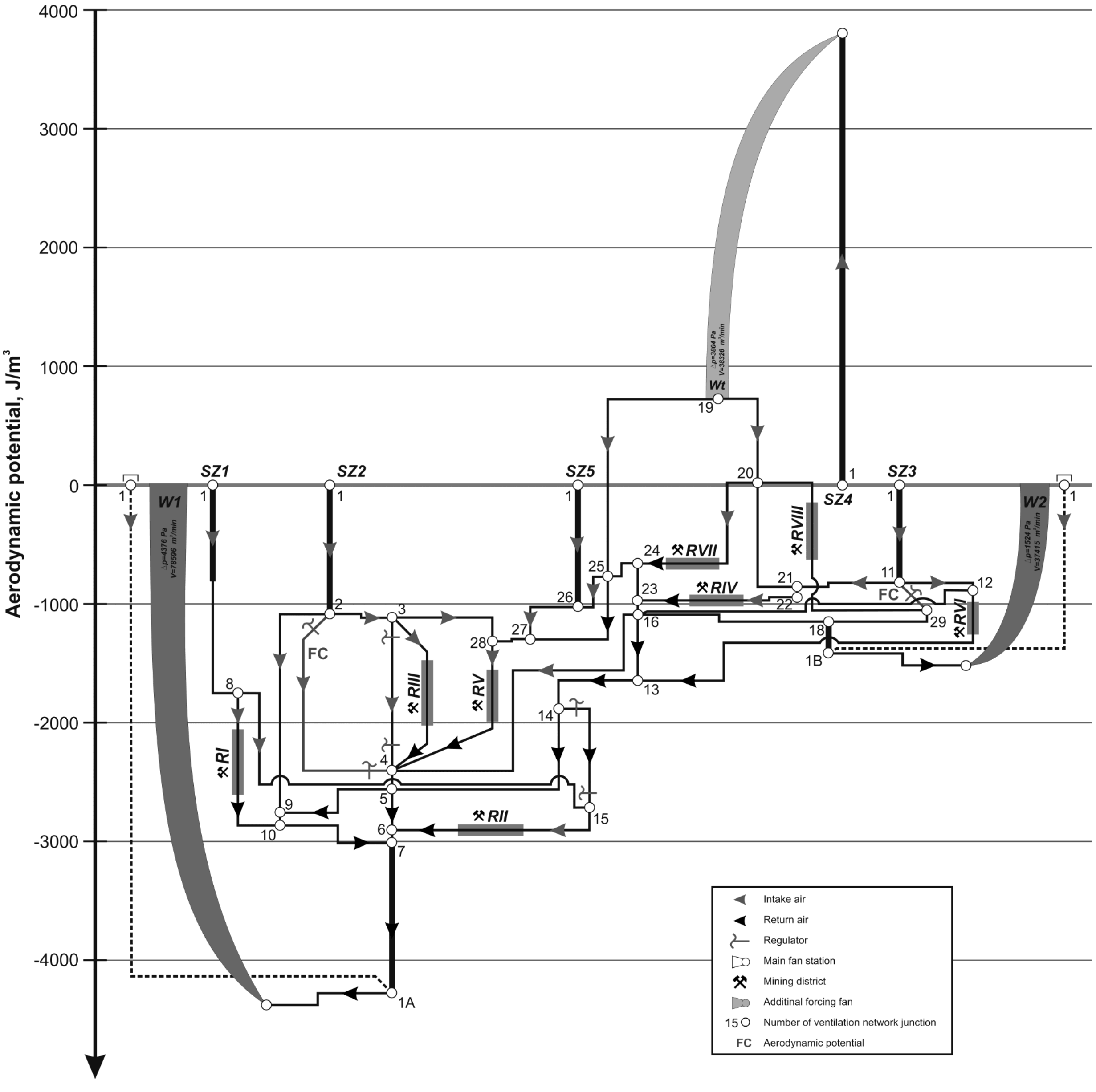

Fig. 6 Graph of aerodynamic potential in nodes of ventilation network (variant with additional forcing fan)

The calculations shows that installing additional forcing fans cause changing in distribution of air especially in branches and mining districts located near the shaft with installed fans. In other mining districts influence of forcing fans is not so significant. Conducted analysis shows that the highest airflow rate were supplied to the mine through the shaft with additional forcing fans.

Forcing fans can be employed to intensify ventilation in a specific group of airways. Nonetheless, possible disturbances of airflow distribution in the other branches of the network have to be taken into consideration. The increase in the total amount of air flowing through the entire ventilation system depends on the complexity of the network and the characteristic curves of fans installed at upcast shafts. Conducted analysis show also that rising the airflow in shaft with additional forcing fans causes descending of airflow in other downcast shafts.

In Figure 6 are presented the graph represents aerodynamic potential in the nodes of ventilation network for variant with additional forcing fan. In Figure 7 are presented the comparison of operating points for the analysed variants.

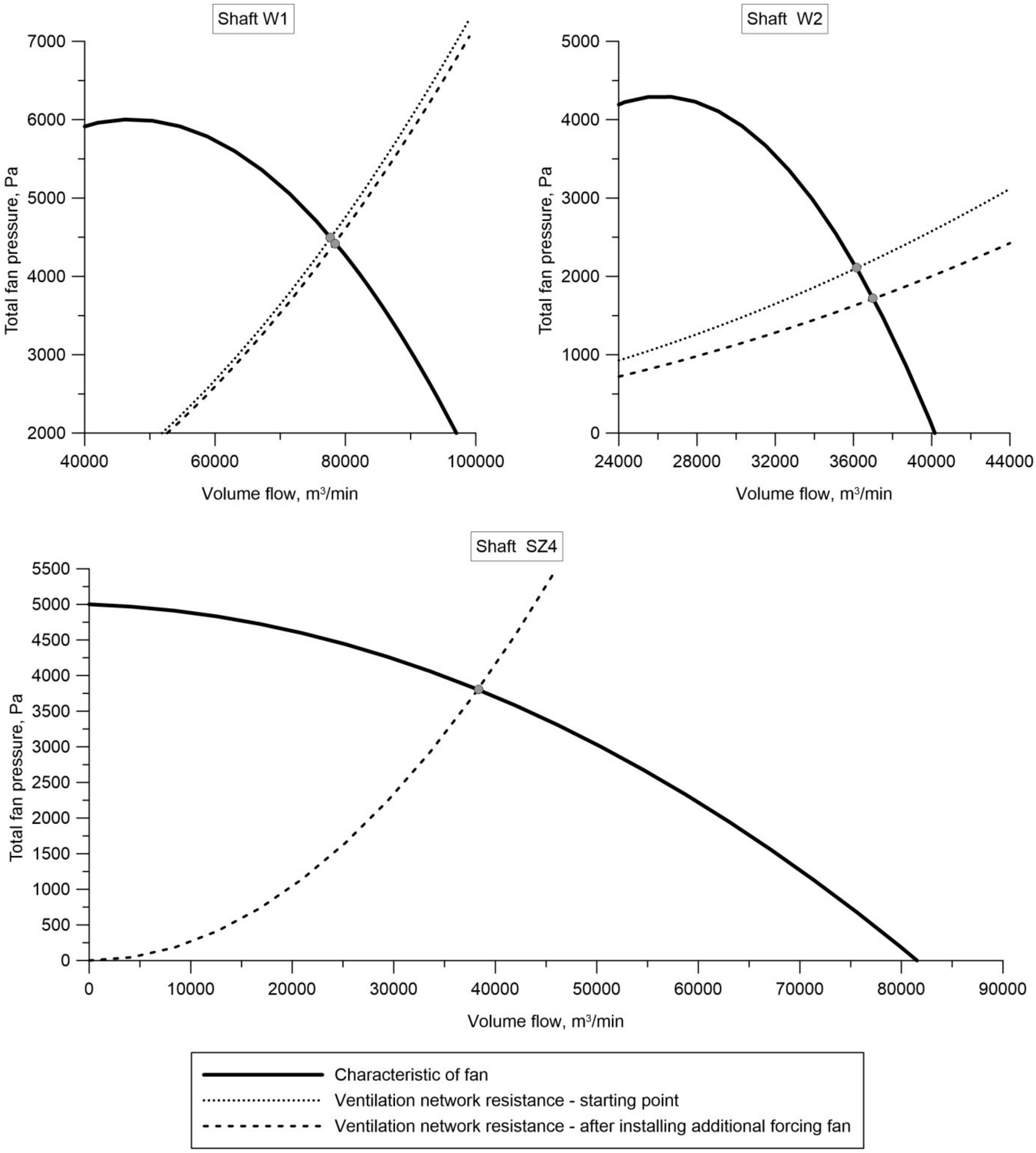

Fig. 7 Comparison of operating points for the analysed variants

CONCLUSION

The progress of mining fronts in deep underground mines, which is a consequence of deposit depletion and opening new mining fields, calls for drilling new shafts, combined with extending the existing ventilation network. In recent years also some mining areas were connected. As a result, the ventilation network becomes increasingly complex. Booster fans are often employed in mines, primarily as means of controlling airflow distribution in the ventilation network by overcoming the pressure drop. However, their placement and available capacity does not increase the total amount of air carried into the system.

The aim of installing forcing fans in the primary ventilation system of a multiple-fan mine is to step up the primary ventilation capacity. Forcing fans can be employed to intensify ventilation in a specific group of airways. Nonetheless, possible disturbances of airflow distribution in the other branches of the network have to be taken into consideration. The increase in the total amount of air flowing through the entire ventilation system depends on the complexity of the network and the characteristic curves of fans installed at upcast shafts.

The calculations of airflow distribution made for a real ventilation network have revealed that installing a forcing fan at one of the downcast shafts will cause only a limited increase in the total amount of air supplied to the mine. The scale of the increase depends on the equivalent resistance of the network and the characteristic curves of all fans. The implementation of fans forcing the air into the ventilation network may fail to bring the expected economic advantages. Nevertheless, although the amount of air passing through the entire network cannot be increased considerably, a positive result has been observed as the ventilation capacity increased of primary intake airways adjacent to the downcast shaft with an installed forcing fan. Calculations show significantly increasing of airflow rate in working areas near the shaft with additional forcing fan.

In push-pull systems with multiple main fans, it is vital to select forcing fans with characteristic curves matching those of the existing exhaust fans to prevent undesirable mutual interaction. In complex ventilation networks it is necessary to calculate distribution of airflow (especially in networks with a large number of installed fans).

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