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THE JUSTIFICATION OF NEW TECHNIQUE VENTILATION AT CONSTRATION OF WORKING WITH TWO EXITS IN SOIL SURFACE

The need to maintain the specified atmospheric parameters inside workings at performance of erection work is still critical even during the closing stages, i.e. when through-flow ventilation is already in place. This task is becoming especially important when vehicles and equipment driven by internal combustion engines are used in mining operations. Application of traditional ventilation schemes with fans located inside the tunnel does not seem rational as it decreases mobility of the mining and construction equipment. It is known that fans located at some distance from the brow and creating a free airflow directed perpendicular to the brow face are often used in tunnel fire tests. However, they do not provide any justified methods to select parameters of such fans. The investigation included complex theoretical and experimental studies. The resulting dependences render it possible to select ventilating equipment parameters for the ventilation schemes with the draught source located outside of the working.

Key words: *venturi jets, jet fan, longitudinal ventilation, through underground workings, motorway tunnel, construction and installation activities, calculation method*

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Introduction

Construction of workings involves two main stages that determine specific features of their ventilation. During the first stage when excavation is done with dead end headings, ventilation is arranged with ventilation tubes. Parameters of these ventilation systems are calculated using well-proven methods and do not pose any challenges.

The second stage, when workings driving is completed and through-flow ventilation is introduced, is characterized with difficulties in establishing of steady air movement due to significant impact of the natural draught [4, 7, 17] as well as inefficiency of traditional way of fan location inside the workings [9, 10] where they impede movement of vehicles and other equipment [5, 20].

It is known that during the fire tests air is delivered into the tunnels using the so-called venturi jets, i.e. fans that are located at some distance from the tunnel portals and that create a free airflow directed perpendicular to the tunnel face [6].

Our research aimed to establish a functional relationship between the venturi jet performance curves and air velocity in the workings. For this task, we used physical and mathematical modelling of aerodynamic processes in tunnels with a venturi jet used as the draught source.

Physical modeling

Physical modeling was preceded by analysis of factors that affect the air velocity in the working (U_w) when a venturi jet located outside of the working is used as the draught source. The following determining factors were established: internal diameter of the fan hole (d_f), output air velocity (V_f), tunnel length (L_w), distance from the venturi jet location to the brow (L_{loc}), hydraulic diameter of the working (D_w), air density (ρ_a); full aerodynamic drag factor of the workings (ζ_w):

$\zeta_w = 1 + \xi_{ext} + \lambda_w \frac{L_w}{D_w}$, where λ_w is the friction factor; ξ_{ext} is the local drag coefficient of the working intake section [8, 10].

The following similarity criteria were determined for physical modelling and processing of its results using the dimensional theory: $Z_1 = \frac{8}{\pi^2}\zeta_w \frac{d_f^4}{D_f^4}$; $Z_2 = D_w/d_f$; $Z_3 = L_{loc}/d_f$ [1].

The dimensionless air velocity in the working U_w/v_f as a function of these similarity criteria can be expressed in the following way:

$$U_w / V_f = F\left[(Z_1)^x \cdot (Z_2)^m \cdot (Z_3)^n\right]. \quad (1)$$

The performed assessment showed that for conditions of real tunnels with the lengths from 1,000 to 3,000 m, the internal diameters of 7.5–8.4 m and the friction factors of 0.02–0.033, ventilated with a free airflow created by venturi jets with the diameter of 1.6–2 m and located 10–60 m from the brow, the similarity criteria will vary within the following ranges: Z_1= (0,013–0,07), Z_2 = (3–5), Z_3 = (5–30).

Geometrical dimensions of the bench model were defined based on the need to observe all the geometrical similarity principles and with due account for similar structural parts of the model and the prototype. The tunnel was modelled using an acrylic plastic tube with the length $L_{w,0}$ = 1.5 m and the cross-section of 0.0066 m^2. The friction factor determined for a similar tube was 0.029 [5, 13]. Given these conditions for the model with the output diameters of the venturi jet of 0.027 m, 0.03 m and 0.035 m, values of Z_1, Z_2 and Z_3 will equal 0.012–0.050; 2.66–3.35; 1.48–22.22 respectively, i.e. they fall within the range of values measured in real workings. Impellors, that are used in aeromodelling and which design is similar to the venturi jets, were used in model experiments to imitate the venturi jets that are intended for use in real conditions. The impellors were fitted with frequency converters (**Fig. 1**), which helped to change the impellor rotation speed and control the output air velocity within 8–40 m/s [11, 19].

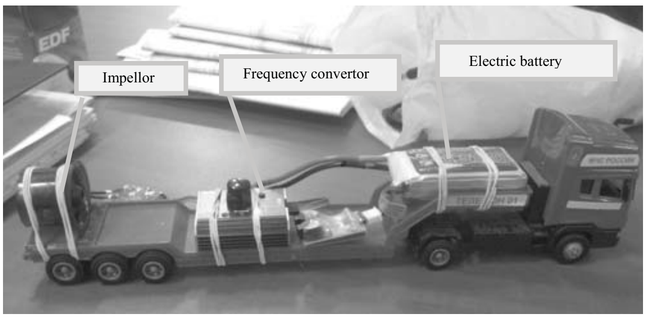

Fig. 1. Layout and design of setup up for model experiments

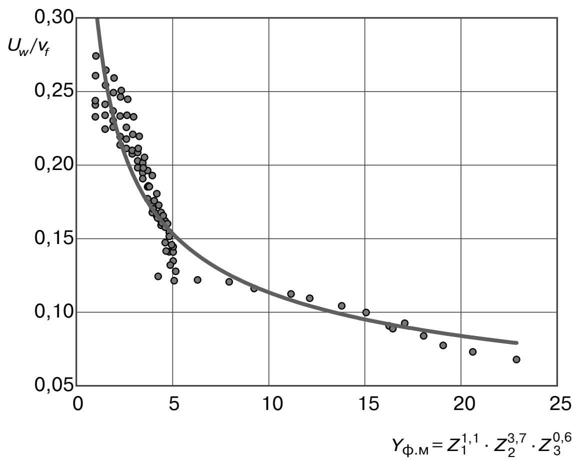

Fig. 2. Dependence diagram of dimensionless air velocity versus argument $Y_{ph.s}$

Dependence of the air velocity at the output of each impellor type on the rotation speed was established by measuring the air velocity inside a pipe attached to the impellor and characterized with negligible aerodynamic drag.

To make sure that the similarity criteria of the model experiment match the similarity criteria of real tunnels, it was suggested that the model resistance is deliberately increased by fitting a flap at its output. Decreasing the effective section of the air flow at the model output helps to increase the full aerodynamic drag factor of the model ζ_T due to the local drag factor of the flap ξ_g, $\zeta_w = \frac{}{2 \quad 4}\left(+ \xi_{ext} + \xi_g + \lambda_w \frac{}{} \right)$ [13]. Comparing correlations of full aerodynamic drag factor ζ_T of the models with and without flaps, we can easily derive an equation that would link the drag factor of the flap with

$$\xi_g = \frac{\lambda_T}{D_w}\left(L_{w,i} - L_{w,0}\right). \tag{2}$$

Thereby, each position of the flap at the output of the tunnel model will correspond to a specific tunnel length in terms of the aerodynamic drag.

As the air velocity in the model is essentially determined by its aerodynamic drag, we can use the model with the tunnel length $L_{w,0}$ to create air flow parameters typical of tunnels with unspecified length $L_{T,i}$ by setting the desired value of the model length and subsequently calculating value ξ_g using equation (2).

In order to find the local drag coefficient of the flap in its various positions with reference to the working model cross-section, we performed simultaneous measurements of the mean air velocities in the working model and loss of air pressure at the flap.

The physical modelling procedure consisted in impellor positioning at various distances from the tunnel portal in parallel with its axis and delivery of the air jet to the portal with air velocity measurement at its exit.

A heat-loss anemometer was used to measure changes in the air velocity in all experimental series, while measurements of the air pressure loss were made by a pressure differential gauge.

The measured data were processed using non-dimensional similarity criteria Z_1, Z_2 and Z_3 and were represented as a characteristic curve of the dimensionless air velocity $\frac{U_w}{V_f}$ versus argument $Y_{phys.mod} = Z_1^x \cdot Z_2^m \cdot Z_3^n$. The x, m, n values.

Upon transformation of this dependence with account for numerical values of the power of numbers Z_1, Z_2 and Z_3, the equation for calculation of the air velocity with a venturi jet installed in front of the tunnel portal and the air jet delivered to its cross-section will take the following form:

$$U_w / V_f = 0.31 \cdot Z_1^{-0.48} \cdot Z_2^{-1.63} \cdot Z_3^{-0.26}. \tag{3}$$

Based on the physical modelling results, a conclusion was also made that at a certain distance between the venturi jet location and the tunnel portal, the air velocity reaches its maximum. This maximum velocity decreases both with increasing or decreasing distance to the tunnel portal.

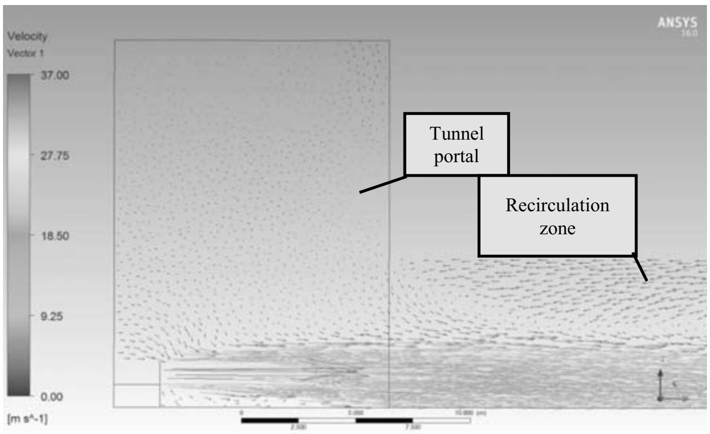

Fig. 3. Air jet velocity vectors at working entrance (L_{loc} = 10 m, d_f = 1.0 m, V_f = 35.6 m/s)

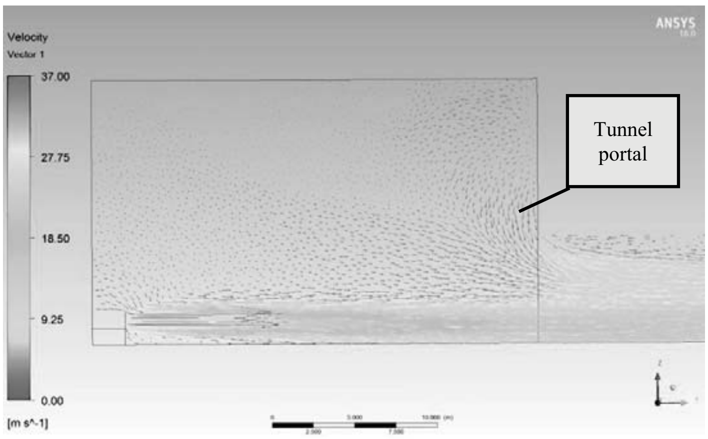

Fig. 4. Air jet velocity vectors at working entrance (L_{loc} = 25 m, d_f = 1,0 m, V_f = 35,6 m/s)

Mathematical modelling

In order to verify the physical modelling results as well as to account for the impact of natural draught ($h_{n.d}$) that acts against the air movement, we performed mathematical modelling of aerodynamic processes taking place when a free air jet created by a venturi jet located at the brow is acting upon the air flow in the working. Mathematical modelling of the aerodynamic processes was done with the Ansys CFX software package [2, 3, 14, 15, 16].

Similar to physical modelling, a number of scenarios were considered that take into account various aerodynamic and geometrical parameters of venturi jets located at various distances from the brow that have different lengths.

The input data used in mathematical modelling are given in **Table**.

Numerical values of aerodynamic and geometrical parameters used in mathematical modelling

Parameter	L_{loc}, m	L_w, m	d_f, m	U_w, m/s	$h_{n.d}$, Pa
Numerical value	10; 25; 40	150; 320; 740; 1100; 2730	1.0; 1.6	35.6; 32.8	0; 10; 20

Calculation results for each of 64 various scenarios were presented as air velocity and pressure profiles at the working entrance and during its movement through the working.

Analysis of the mathematical modelling results demonstrated that moving the venturi jet closer to the brow decreases its operational efficiency due to an air recirculation zone that is created close to the portal (**Fig. 3**). The length of this recirculation zone is decreasing when the venturi jet is moved away from the brow, and tends toward zero at the distances exceeding 25 metres (**Fig. 4)**. Complete stabilization and straightening of the air draught takes place at the distance of 100–120 m from the brow with the incoming air jet.

Results of mathematical modelling in the absence of the natural draught are given in the same format as the corresponding dependence (3) (**Fig. 5**).

Their correlation with the physical modelling data (**Fig. 2**) shows that the discrepancy does not exceed 15%.

$$U_w / V_f = 0.43 \cdot Z_1^{-0.60} \cdot Z_2^{-2.56} \cdot Z_3^{-0.06}. \quad (4)$$

In order to assess the impact of natural draught ($h_{n.d}$) on the air velocity in the tunnels, we performed additional mathematical modelling whereby the natural draught was taken as acting against the air stream created by the venturi jet and its value was changing within 0–20 Pa [6, 7, 17].

In processing of the mathematical modelling data, the natural draught impact on dimensionless air velocity in the tunnel was taken into consideration by introducing similarity criterion $Z_4 = h_{n.d}/\rho_a \cdot v_f^2$.

Modelling results are given as a dependence diagram in **Fig. 6**.

The dependence relative to the dimensionless air velocity in the tunnel and describing mathematical modelling results with the correlation ratio of 0.93 is as follows:

$$U_w / V_f = 0.087 \cdot Z_1^{-0.93} \cdot Z_2^{-4.00} \cdot Z_3^{-0.09} \cdot Z_4^{-0.47}. \quad (5)$$

On the basis of dependence (5) critical values of natural draft at which the chosen type of the venturi jet allows to provide the acceptable ventilation mode can be established.

Results of calculations of air velocity in working at the venturi jet location at distance of 20 m from her brow (diameter of exhaust outlet of 1,6 m, initial speed of free stream 35 m/s) are presented in **Fig. 7** [6,19].

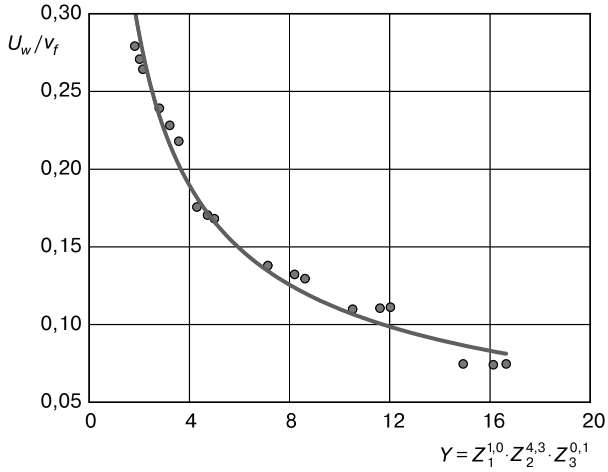

Fig. 5. Dependence of dimensionless air velocity in the tunnel versus argument $Y_{m.s}$ (in natural draught absence)

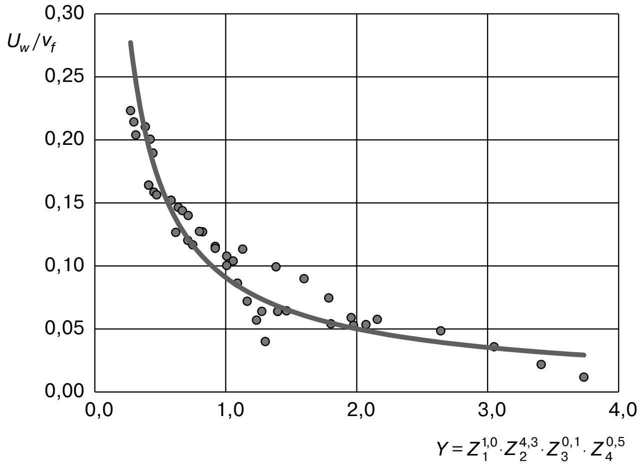

Fig. 6. Dependence diagram of dimensionless air velocity versus argument $Y_{m.s}$ (with account for natural draught)

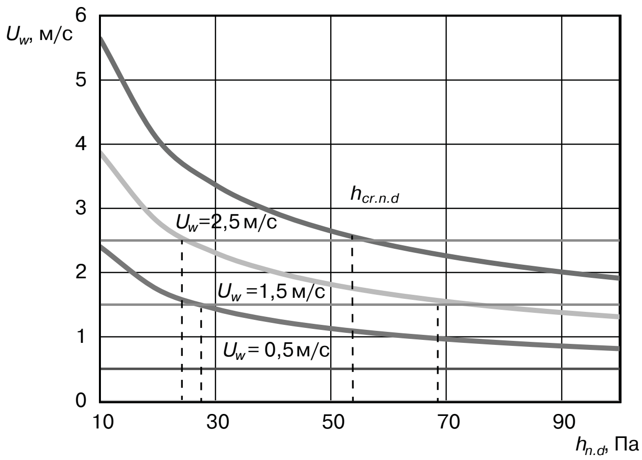

Fig. 7. Critical values of natural draft ($h_{cr.n.d}$) at which in workings the acceptable ventilation mode isn't provided (red line – L_w = 500 m; green line – L_w = 1000 m; blue line – L_w = 2000 m)

Conclusions

The performed complex theoretical and experimental studies justified the possibility to use venturi jets located at the brow as the draught source for tunnel ventilation during construction and assembly operations provided a through air flow is present.

The obtained dependences render it possible to determine the aerodynamic parameters and rational location of the venturi jets with reference to the brow.

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