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NÁVRH A IMPLEMENTACE SYSTÉMU REGULACE VĚTRÁNÍ TUNELU BLANKA V PRAZE

DESIGN AND IMPLEMENTATION OF THE VENTILATION CONTROL SYSTEM OF THE BLANKA TUNNEL IN PRAGUE

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ABSTRAKT

Ventilace je jedním z nejdůležitějších bezpečnostních prvků v silničních tunelech. Jedná se o nezbytné opatření v případě vzniku požáru, neboť hraje důležitou roli v případě evakuace. Systémy ventilace v silničních tunelech jsou primárně určeny pro řízení šíření kouře v případě požáru a také se jedná o účinný nástroj pro redukci znečištění uvnitř tunelu. Článek popisuje návrh algoritmů ventilace budovaného tunelového komplexu Blanka v Praze, České republice, který se po svém dokončení stane největším městským silničním tunelem ve střední Evropě s celkovou délkou přes 5 kilometrů. Systém ventilace tunelu je poměrně složitý a je složen ze dvou podsystémů – podélný a příčný. Článek prezentuje návrh řízení jak požární, tak provozní ventilace, přičemž návrh obou regulátorů je navržen na základě zjednodušených matematických modelů. Optimalizace spotřeby elektrické energie během provozu je nezbytná z důvodu vysokých předpokládaných provozních nákladů.

ABSTRACT

Ventilation is one of the most important safety elements in road tunnels. It is a necessary measure in the case of fire, as it plays an important role during a fire evacuation. Primarily, ventilation systems in road tunnels are intended for the control of smoke propagation in the case of fire, and secondly, they are powerful tool to dilute the pollution of car exhaust gases inside the tunnel. The paper describes the design of ventilation control algorithms in the constructed Blanka tunnel in Prague, Czech Republic, which will be the largest city tunnel in Central Europe with the total length over 5 km. The paper presents the design and the implementation of both fire and operational ventilation control. The design of both controllers is based on simplified mathematical models of airflow velocity and pollutant concentrations. Energy consumption optimization during the operation is necessary because of high anticipated operating costs.

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1 Introduction

After fire catastrophes in road tunnels in 1999 (Mont Blanc tunnel – 39 deaths, Tauern Road tunnel – 12 deaths) and in 2001 (St. Gotthard tunnel – 11 deaths, Gleinalm tunnel – 5 deaths), governments and tunnel experts began to focus more on the tunnel safety [14].

Ventilation is one of the most safety important elements in road tunnels – it is a necessary measure in the case of fire, as it plays an important role during evacuation. Firstly, the ventilation systems in road tunnels are mainly intended for the control of smoke propagation during fire situations, and secondly, they are a powerful tool to dilute the pollution of car exhaust gases inside of the tunnel. In recent years, the necessity for tunnels situated in the built-up area (especially city tunnels) becomes more common in order to maintain the environment both inside and outside tunnels [10]. For these reasons, the reliable and satisfactory control of ventilation is very important.

On the other hand, the ventilation in road tunnels is a technology, which requires huge electricity capacities – ventilation and lighting systems form the major part of energy costs in tunnels. Payments for electricity bills can climb up to hundreds of thousands Euro per year. There is an interest in the minimization of electricity consumption especially in the case of complex road tunnels (long tunnels with connected junctions). Example of such tunnel is the constructed Blanka tunnel in Prague.

2 About the Blanka tunnel

The Blanka tunnel is one of the largest underground structures in the Czech Republic with the total length about 5.5 km. It forms the northwest part of the Prague City Ring. The tunnel has two tubes (northern and southern) with one-way traffic in each tube. There are four grade separated junctions in both tubes (Malovanka, Prašný most, U Vorlíků and Trója). The route passes under urbanized environment on the boundaries of the historical Prague center. It is routed in driven and cut-and-cover tunnels. The whole construction is divided into three tunnels, which are connected to these grade separated junctions – Brusnice, Dejvice and Královská obora [19].

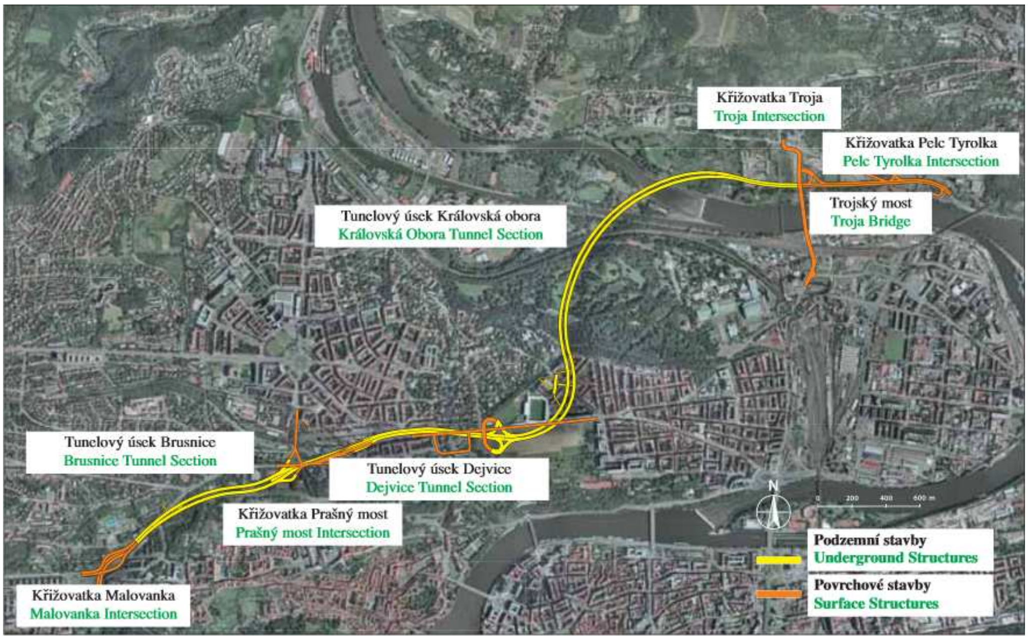

Fig. 1 Situation placement of the Blanka tunnel in Prague [20]

The tunnel tubes are situated inside the city, build-up area and therefore there are significant requirements on minimization of car exhaust gases from exit junctions to the nearby environment and energy consumption optimization during the operation is necessary because of high costs of energy.

3 Ventilation requirements of the Blanka tunnel

As the Blanka tunnel has the semi-transverse system of ventilation, the ventilation system is relatively complex. The longitudinal system is comprised of jet fans – there are 88 jet fans (in both tubes together) and the transverse ventilation system consists of 6 ventilation machine rooms – Trója (TGC6), Letná (TGC4), Prašný most (TGC2), Špejchar (TG7), Střešovice (TGC1) and Malovanka. The ventilation machine rooms Prašný most and Špejchar are intended only for the fire ventilation. The ventilation machine rooms are primarily intended for smoke extraction and secondly they provide supply of fresh air into the tunnel and extraction of polluted air from both tubes. The ventilation machine rooms are equipped with axial flow fans and they have higher power in comparison with jet fans. There are together 30 axial flow fans in the ventilation machine rooms.

The ventilation of the Blanka tunnel is divided into two independent states of operation. The first one represents the operational ventilation and the other one is the fire ventilation.

3.1 Operational ventilation

The operational ventilation can run in five different modes – natural airflow, control of indoor environmental quality, first level of protection, second level of protection and preventilation mode:

- Natural airflow – The tunnel is usually ventilated naturally, longitudinally thanks to the piston effect of passing cars through the tunnel. There is an assumption that this state will occur in night hours and at weekends during the real operation.
- Indoor environmental quality control – In certain cases (e.g. congestion), limit values of pollutant concentration can be exceeded. The operational ventilation must provide the supply of fresh air into the tunnel and dilute polluted air. The limit values of pollutant concentrations for the operational ventilation of the Blanka tunnel were determined according to the recommendations of the World road association PIARC [12] and CETU [5], in order to satisfy legal standards of the Czech Republic. The limit values of the pollutant concentrations are depicted in Tab. 1.

Tab. 1 Limit values of pollutant concentration in the Blanka tunnel.

Pollutant	**Limit value**
Nitrogen oxides (NO_x)	10 mg/m^3
opacity	5 km^{-1}

In recent years, CO emissions per vehicle have reduced significantly thanks to the growth of catalysts, therefore carbon monoxide is no longer the dominating factor in the ventilation design in many European countries [13]. The design of operational ventilation is focused primarily on NO_x emissions and visibility and there will be only measurements of NO, NO_2 and visibility in the Blanka tunnel.

- First level of protection – In the tunnel junction Malovanka, there will probably be increased pollution produced by outgoing cars from the northern tunnel and from the already operated tunnel Strahov. Minimization of exhaust gases from the exit portal Malovanka is the most complex process from the operational ventilation point of view. The state of the first level of protection is illustrated in Fig. 2. The airflow in the northern tunnel must be decelerated with the help of the ventilation machine room Střešovice and jet fans in the corresponding section, such that concentrations of car exhaust fumes from the exit portal Malovanka will be decreased.

- Second level of protection – The second level of protection is more energy demanding than the first level of protection, but assures full protection of the exit portal Malovanka. The ideal state of the second level of protection is demonstrated in Fig. 2. There are dampers between both tubes on two places in the tunnel and the transfer machine room Malovanka. These dampers together with the transfer machine room Malovanka transfer polluted air from the northern to the southern tunnel. This measure helps to keep the exit portal Malovanka in the northern tube in lower pressure against the outside of the tunnel. In this level of protection, there is also an additional requirement on the minimization of exhaust gases from the other exit tunnel junctions. There is a measurement of nitrogen oxides outside of the tunnel in the grade separated tunnel junction Malovanka. This measurement together with traffic situation in the northern tunnel will determine which level of protection will be activated in the real operation.
- Pre-ventilation mode – The pre-ventilation mode is activated in the case of suspicion of fire (e.g. stationary vehicle, increased concentration of opacity) in tunnel sections. Where the pre-alarm is detected, special requirements on the longitudinal airflow velocity are desired. The jet fans in the tunnel should satisfy that the value of the longitudinal airflow velocity in the tunnel section will not be lower than 1.2 m/s. The required value of the airflow velocity is understood as a critical for the smoke propagation.

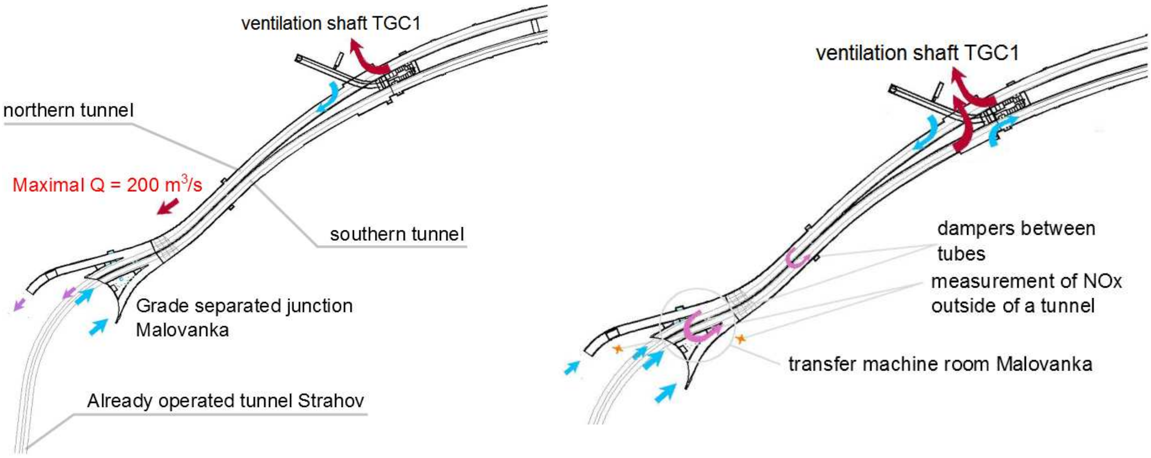

Fig. 2 Schematic situation of the first (on the left) and second level of protection (on the right) [24]

3.2 Fire ventilation

Fire ventilation mode is activated in the case of fire detection in one of the 125 fire sections (in both tubes together). There are three types of fire detectors in the Blanka tunnel. The first group forms linear heat detectors, second group consists of smoke detectors and the last detectors are cameras. In city tunnels, there can be more frequent congestions or stop and go situations, moreover, the maximum allowed speed in city tunnels is usually less than in highway tunnels and in the case of occurred fire, there can be blocked vehicles on both sides of fire origin. The fire ventilation mode of the Blanka tunnel is divided into two phases [23]:

1) First phase – to support evacuation of people,
2) second phase – start-up for firefighters.

In the first phase of fire, hot smoke rises to the ceiling in the tunnel and it is urgent to support evacuation of people and avoid smoke propagation in the direction of blocked vehicles ahead of the fire origin and to keep people in smoke-free environment as long as possible [11]. The longitudinal airflow velocity ahead of the fire origin not higher than approximately 1.2 m/s (differs according to different tunnel cross-section area) ensures that smoke propagates only on one side from the fire origin and does not propagates in the direction of blocked vehicles, above that the smoke layer is maintained and separated from the fresh air layer. It is the optimal situation and is well known as a smoke stratification [8]. Ventilation machine rooms provide smoke extraction through fire dampers located under the ceiling and thereby help to control the longitudinal airflow velocity.

The second phase starts after successful evacuation and usually after the arrival of firefighters. It is important to ensure the clear way to the fire origin in the second phase, therefore the longitudinal airflow velocity ahead of the fire origin in the second phase should be larger than in the first phase (around 2.5 m/s). The aim of the second phase is to extract, if possible, the most part of the smoke from fire.

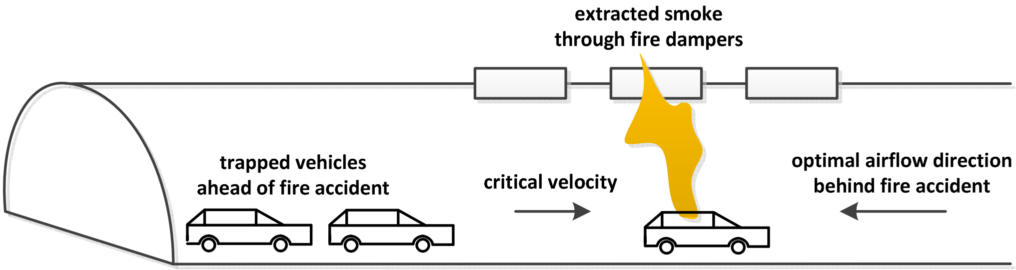

Fig. 3 Schematic situation of fire ventilation control [22]

4 Simulation model of ventilation

In recent years, simulation models of real complex processes have become popular thanks to improving computer technology and computing power. Based on these models, the controllers can be tuned and much time associated with the controller tuning in the real process can be spared. Our suggested approach is to use the mathematical model of a tunnel, which describes the dynamics of airflow and pollutant concentrations in details, to design the ventilation controllers. This model involves all important effects, which influence the physical behavior of the tunnel – air friction, piston effect of vehicles, propagation of pollutant concentrations, etc. Two simulation models have been developed for the design of ventilation controllers in the Blanka tunnel – airflow velocity model and pollutant concentrations model.

4.1 Airflow velocity model

For the Blanka tunnel, the simplified description based on the Bernoulli’s equations and the continuity equations was chosen to describe the airflow in the tunnel one-dimensionally. For the purpose of the mathematical model of airflow, the tunnel is divided into ventilation sections. A ventilation section is a part of the tunnel, which has constant geometry. It means there is constant cross-section area, slope of the road, hydraulic diameter of the tunnel, etc. Ventilation sections of the tunnel are mathematically connected by the continuity equations [6] and [9]

$$\sum_i Q_i = 0 \,, \tag{1}$$

where Q_i [m^3/s] is airflow volume in the „*i-th*” section, which enters in the node or leaves the node, respectively. The Equation (1) describes also the connecting or dividing flows in the case of a tunnel junction as demonstrated in Fig. 4. There are three ventilation sections in this figure – section 1, 2 representing the main tunnel route and section 3 representing the exit ramp. This case can be described by Equation (2) as follows

$$Q_1 - Q_2 - Q_3 = 0\,, \tag{2}$$

The similar situation is occurring in the case of ventilation machine rooms. Ventilation machine rooms provide the supply of fresh air in the tunnel or extraction of smoke or polluted air from the tunnel through dampers. The extracted mass through a ventilation machine room has to fulfil Equation (1).

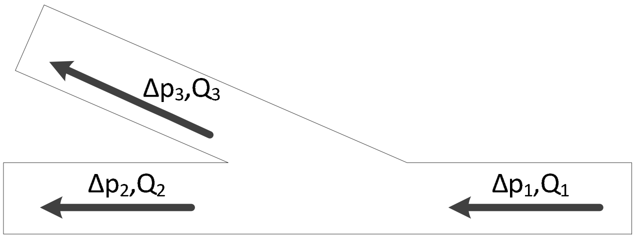

Fig. 4 Schematic view of an exit tunnel junction

The other equations that describe the airflow dynamics in the tunnel are Bernoulli’s equations. The Bernoulli’s equation states that pressure changes in the individual tunnel outlets must equal. The exit tunnel junction depicted in Fig. 4 satisfies the following conditions [15]:

$$\begin{aligned} \Delta p_1 + \Delta p_2 &= 0 \\ \Delta p_1 + \Delta p_3 &= 0 \end{aligned}\,, \tag{3}$$

where Δp_i [Pa] denotes the total pressure change in the respective section.

In tunnels, there are many influences, which cause changes of the total pressure change Δp_{tot} [Pa] in Equation (4). On one hand, there are pressure gains (sources) like piston effect of passing vehicles through the tunnel, or jet fans effect. On the other hand, there exist pressure drops, which are caused by fluid friction or connecting and dividing flows behind the tunnel junction. The total pressure change in the respective tunnel section can be expressed as

$$\Delta p_{tot} = \pm \Delta p_{pist} \pm \Delta p_{fans} - \Delta p_{fric} - \Delta p_{area} - \Delta p_{mom}\,, \tag{4}$$

where Δp_{pist} means the piston effect of vehicles, Δp_{fans} is the pressure effect of jet fans, Δp_{fric} denotes the pressure drop due to the friction effect, Δp_{area} are pressure drops caused by local losses (constriction, extension, flow division or connection, etc.) and Δp_{mom} expresses the airflow inertia. Positive signs in Equation (4) express pressure gains and negative signs denote pressure drops. Equation (4) is built for each ventilation section of the tunnel.

The pressure change due to the piston effect depends on the intensity and velocity of passing vehicles through the tunnel [4]

$$\Delta p_{pist} = \frac{1}{2} \rho \frac{\sum_i C_v \mathrm{A_v} N_i}{\mathrm{A_T}} (v_{car} - v_{air})^2\,, \tag{5}$$

where ρ is air density, considered as 1.23 kg/m^3, v_{air} [m/s] is the longitudinal airflow velocity in the respective ventilation section, $\mathrm{A_T}$ [m^2] is the tunnel cross-section area, v_{car} [m/s] is the average velocity of vehicles, N_i [-] is a number of vehicles in the tunnel of the respective type, $\mathrm{A_v}$ [m^2] is the average head surface area of the respective vehicle type, $\mathrm{C_v}$ [-] is the coefficient reducing the average head surface area of the vehicle depending on the average vehicles velocity. The simulation distinguishes three types of vehicles – passenger cars, vans and trucks.

The member Δp_{fans} describing an influence of jet fans in the tunnel can be calculated as follows [7]

$$\Delta p_{fans} = \frac{\eta_{JF} \rho Q_{ref}{}^{2}}{n_{ref}{}^{2} A_{JF} A_{T}} n^{2} + \frac{\eta_{JF} \rho Q_{ref}}{n_{ref} A_{T}} n \cdot v_{air} , \tag{6}$$

where η_{JF} [-] is the power efficiency of a jet fan, Q_{ref} [m^3/s] is the nominal airflow through a jet fan, A_{JF} [m^2] is the rotor diameter, n_{ref} [1/min] is the maximal rotational speed of a fan rotor (RPM). These parameters are all catalogue data. The important symbol in Equation (6) is n [1/min], it is the current rotational speed of a fan rotor.

The pressure drop caused by air friction (Equation (7)) depends especially on wall roughness [4]

$$\Delta p_{fric} = \frac{1}{2} \rho \lambda \frac{L}{D_h} v_{air}{}^{2} , \tag{7}$$

where L [m] is the length of the particular ventilation section, D_h [m] is the hydraulic diameter of a tunnel and λ [-] is a friction factor, which can be calculated according to the Swamee-Jain equation [21].

The term Δp_{area} represents local pressure drops due to tunnel geometry changes depending on tunnel areas, shape of transition or direction of airflow and can be generally expressed as

$$\Delta p_{area} = \frac{1}{2} \rho \xi v_{air}{}^{2} , \tag{8}$$

where ξ [-] are loss coefficients depending on the tunnel cross-section area. This kind of pressure drops involves also pressure changes caused by connecting and dividing streams [4].

The last member Δp_{loc} in Equation (4) represents the momentum of airflow [3]:

$$\Delta p_{mom} = \rho L \frac{dv_{air}}{dt} . \tag{9}$$

The pressure change due to change of altitude of the tunnel can be neglected in our case, because pressure changes due to altitude change in the Blanka tunnel are negligibly small against the other pressure effects in the tunnel. The mentioned pressure change is often considered by mountain highway tunnels, where the differences in altitudes of tunnel portals can be significant [23]. The effect of wind on portals was also neglected thanks to the favorable location of the Blanka tunnel in the built-up area.

The unknown variables in the system of nonlinear equations are airflow velocities in the individual ventilation sections. This system of equations is solved in each step of simulation with the help of numerical tools in MATLAB [25].

4.2 Pollutant concentrations model

Cars passing through the tunnel produce exhaust fumes due to the diesel combustion or combustion of gasoline. The most released gases are nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO) and solids, which increase opacity in the tunnel. Pollutants produced by vehicles depend on emission factor, number of vehicles of the given type, vehicle velocity and volume of air in the given place of the tunnel

$$R(t) = \frac{\sum_{i} N_i(t) E_i v_{car}(t)}{V_{air}(t)} , \tag{10}$$

where $R(t)$[$g/m^3/s$] is the total production of emissions of all vehicles in the tunnel, E_i [g/m] is the emission factor of the respective type of vehicles, V_{air} [m^3] is volume of air in the given ventilation section.

The production of emissions depends, according to Equation (10), on the emission factor. The emission factor E_i depends primary on the vehicle type (passenger car, van, truck), slope of the road and vehicle age. There exist many sources where one can find emission tables including emission factors depending on European emission standard EURO. In Europe, the mostly used emission tables are defined by the World Road Association (PIARC) [13]. The emission factors for the simulation of the Blanka tunnel were determined from the program MEFA, developed by the company ATEM [2], which are very used in the Czech Republic.

The steady-state model of pollutant concentrations has been used for simulation. This model does not require the information about positions of all vehicles in the tunnel. Pollutant concentrations in any ventilation section of the tunnel are given by the simple formula [22]

$$c(i) = \frac{R(i)\mathrm{L}}{|v_{air}(i)|} + c_{amb}(i)\,, \tag{11}$$

where $c(i)$ [g/m^3] is pollutant concentration in the „*i-th*'' time step and c_{amb} [g/m^3] is ambient pollutant concentration, which cannot be neglected in the case of city tunnels.

5 Design of ventilation control

5.1 Operational ventilation control

The control system of the tunnel consists of programmable logic controllers (PLCs). PLCs control individual technologies of the tunnel (lighting, signaling, etc.) and also turn on individual ventilation devices (jet fans, axial fans in ventilation machine rooms) and form the under layer of the whole control system of the operational ventilation. The supervisory layer involves the supervisory system, which is based on the mathematical optimization.

We have developed the static controller that minimizes the electricity consumption and fulfils all requirements stated in Section 3.1. Our developed controller uses the simplified mathematical model of the tunnel described in Section 4. The principle of the controller is such that the resulting control input (adjustment of jet fans and ventilation machine rooms in the tunnel) is calculated based on traffic intensity, velocity and traffic composition to satisfy all requirements on the operational ventilation while respecting the minimization of electricity consumption. Our developed approach is based on the non-linear mathematical optimization, while the goal of the optimization is to find a minimum of a cost function. The cost function for the optimization task of the operational ventilation can be written as follows

$$[v_k, s_k, n_i, Q_j] = \min \sum_{i=1}^{n} P_i(n_i) + \sum_{j=1}^{p} P_j(Q_j) + \sum_{k=1}^{m} \mathrm{a}_k \cdot (v_{air\,k} - s_k)^2 \tag{12}$$

subject to :

i) mathematical model created based on continuity equations and Bernoulli's equations, see Section 4,

ii) physical constraints of jet fans and ventilation machine rooms,

iii) constraints for the desired range of airflow velocity in the individual ventilation sections.

where n_i [-] is required number of jet fans in the „*i-th*" ventilation section, which are to be run, $P_i(n_i)$ [kW] is electricity power of jet fans in the „*i-th*" ventilation section, Q_j [m^3/s] is desired volumetric flow of air of the „*j-th*" ventilation machine room, $P_j(Q_j)$ is electricity power of the „*j-th*" ventilation machine room, s_k is a slack variable corresponding to the airflow velocity in the „*k-th*" ventilation section, $v_{air,k} - s_k$ [m/s] denotes a variance of the airflow velocity in the „*k-th*" ventilation section and a_k is a weight of penalty when crossing the desired zone of airflow velocity.

The control system provides the following operational data to the supervisory system:

- average longitudinal airflow velocity in the individual ventilation sections,
- average values of pollutant concentration (NO_x, opacity),
- traffic data from operation – traffic intensity, velocity and traffic composition.

The supervisory system calculates the optimization task (12) each 15 minutes and provides new set point adjustment for startup of jet fans and ventilation machine rooms to the control system.

5.2 Fire ventilation control

Fire ventilation control must fulfil all requirements mentioned in Section 3.2. The aim of fire ventilation control is to control the longitudinal airflow velocity ahead of the fire origin. The desired airflow velocity (set-point) is determined as 1.2 m/s in the first phase and 2.5 m/s in the second phase. It is also necessary to control the airflow velocity in the tunnel, which is unaffected by fire, to avoid the potential smoke propagation from the affected to the unaffected tunnel through emergency exists. In the unaffected tunnel the set-point value of the airflow velocity is set up on 1.5 m/s against the driving direction.

As mentioned above, in the Blanka tunnel, there are together 125 fire sections and three independent PID controllers are implemented for every fire section in the tunnel:

- controller ahead of the fire incident in the first phase,
- controller ahead of the fire incident in the second phase,
- controller in the unaffected tunnel.

The aim of the fire ventilation control is to achieve the set-point value of airflow velocity as fast as possible and then maintain it within the allowed band. The allowed band should be achieved in 1-3 minutes from the beginning of fire detection [17]. The oscillations during control should be suppressed and reverse of the airflow velocity (in the direction of blocked vehicles) is strictly prohibited.

The algorithm of the discrete-time PID controller, which is suitable for computation by a computer, is quite simple [1]

$$u(t) = \mathrm{K_p} \cdot e\,(t) + \mathrm{K_i} \cdot \sum\nolimits_{i=0}^{t} e\,(i) + \mathrm{K_d} \cdot (e(t) - e(t-1))\,, \tag{13}$$

where K_p is the proportional constant, K_i is the integral constant and K_d is the derivative constant, $u(t)$ [-] is the output of the PID controller updated each 10 seconds – number of jet fans, which are to be run at the *„t-th"* time step, $e(t)$ [m/s] is the control error at the *„t-th"* time step and can be calculated as follows

$$e\,(t) = v_{ref}\,(t) - v_{air}\,(t)\,, \tag{14}$$

where $v_{ref}(t)$ [m/s] is the set-point value of the airflow velocity at any time step t, and $v_{air}(t)$ [m/s] is the measured airflow velocity at any time step t.

The most of industrial controllers do not use the derivative action in practice, because the derivative action is very sensitive to the measurement noise [26]. The measurement noise can generate large variations of the control input and it can be very hazardous for the fire ventilation mode, therefore the derivative constant K_d is equal to zero for all controllers in all fire sections.

6 Evaluation of ventilation control

In this section, we show results of fire ventilation control during complex examinations in the Blanka tunnel, which ran through July to November 2014. The demonstrated fire test was executed in the fire section SM10. This fire section is located in the driven tunnel Královská obora and smoke is extracted via ventilation machine rooms

Trója and Letná. The result of fire test is depicted in Fig. 5 and Fig. 6, the blue line represents the progress of airflow velocity measured by the airflow velocity sensor ahead of the fictive outbreak of fire and the red line shows the desired airflow velocity (set-point). Firstly, the preventilation mode was activated in the beginning of the test around 13:07, while the set-point of airflow velocity was set to 0.9 m/s. As can be seen, the controller was able to keep the airflow velocity in the allowed band 0.9±0.3 m/s during the preventilation mode without any greater oscillations. The first phase of the fire ventilation control started in 13:19, the airflow velocity increased significantly due to the startup of the ventilation machine rooms for the smoke extraction. The PID controller commanded jet fans in the tunnel to break the airflow velocity ahead of the fictive outbreak of fire to desired values. The optimal situation of fire ventilation control was achieved in 4 minutes after fire activation, because the airflow velocity was kept in the allowed band. The second phase of fire ventilation began after 13:26, the set-point of airflow velocity was increased to 1.9 m/s and the power outlet of ventilation machine rooms was raised. Although the airflow velocity oscillated in the second phase, it still kept in the desired band 1.9±0.3 m/s and all requirements on the fire ventilation control mentioned in Section 3.2 were satisfied.

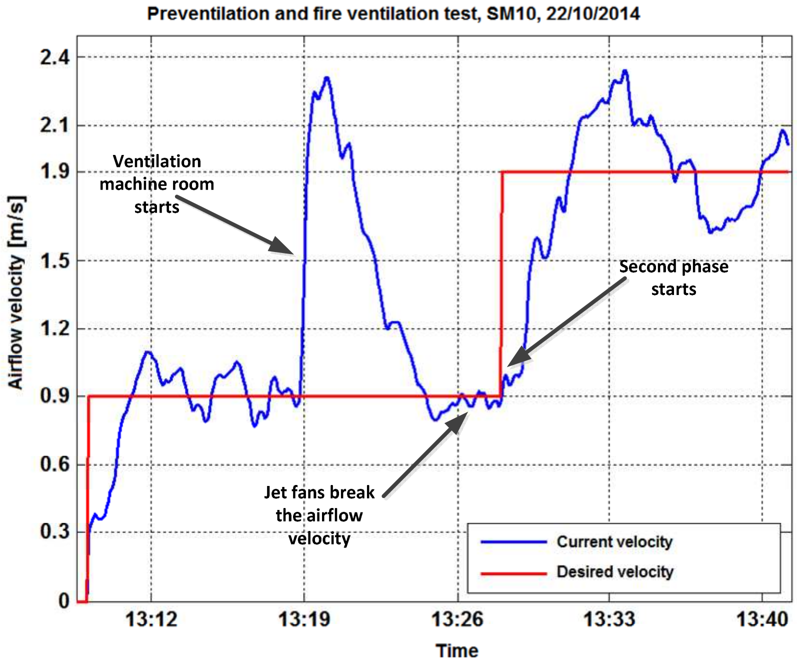

Fig. 5 Evaluation of fire ventilation control in the fire section SM10, progress of airflow velocity ahead of the fictive outbreak of fire

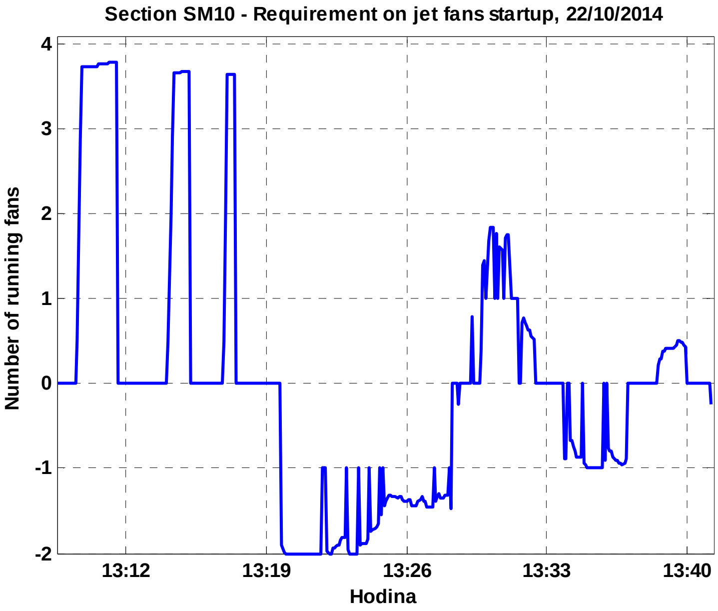

Fig. 6 Evaluation of fire ventilation control in the fire section SM10, progress of startup of jet fans

7 Conclusion

The paper described the design of controllers for the fire and operational ventilation in the Blanka tunnel. Both controllers were pre-tuned on the simplified mathematical model of airflow velocity based on Bernoulli’s equations and continuity equations, then post-tuned during the complex examinations in the tunnel and finally implemented on the real hardware – programmable logic controllers. The advantage of this approach is that many unexpected situations, which can occur during the real operation, can be simulated through these simulation models and controllers can be adapted to these situations. Moreover, it spared much time with the controller tuning, because for complex road tunnels (long tunnels with several grade separated junctions) it is usually very difficult to tune the controller parameters within the complex examinations before opening of the tunnel. Such a complex tunnel is usually divided into several fire sections, which are determined by their own fire sensors – smoke detectors, linear heat detectors or cameras. During the complex examinations in a tunnel one has not usually much time to verify the designed PID controlled of the longitudinal airflow velocity for all detection parts. Moreover, it is quite expensive to make several fire tests in each detection part to fully verify the controller.

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