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Poraba energije v cestnih predorih

Power Consumption in Road Tunnels

KARL PUCHER

V Avstriji je v obratovanju veliko cestnih predorov, nekaj pa jih je tudi v izgradnji ali v fazi načrtovanja. Dolgi predori morajo biti opremljeni z mehanskimi prezračevalnimi napravami. Poraba energije za pogon teh prezračevalnih naprav je lahko še posebej velika v predorih z dvosmernim prometom. Poleg tega je vrtanje skale, potrebno za izgradnjo prezračevalnih cevi v predorih z dvosmernim prometom, zelo drago. Zato je z vidika porabe energije ugodnejša izgradnja dveh predorskih cevi z enosmernim prometom.

In Austria, many road tunnels are in operation, while other tunnels are currently being constructed or planned. Long tunnels need to be equipped with mechanical ventilation facilities. Especially in tubes with two - way traffic the power consumption of these ventilation facilities can be extremely high. In addition, the rock cutting required for the building of air ducts in tunnels with two way traffic demands a huge amount of money. As far as the power consumption is concerned, it is much more favorable to build two tubes with one - way traffic in each.

0 UVOD

Znano je, da je Avstria zelo gorata dežela. Alpske cestne povezave, ki morajo biti prevozne tudi pozimi, zahtevajo izgradnjo dolgih cestnih predorov. Zato ni presenetljivo, da so bili prvi dolgi cestni alpski predori zgrajeni pred več kot dvajsetimi leti, na primer predor Katschberg (5,2 km), predor Radstädter Tauern (6,4 km), predor Gleinalm (8 km), predor Arlberg (13 km) itd. Medtem je bil dokončan tudi predor Karavanke (7,8 km), ki povezuje Avstrijijo in Slovenijo. V zadnjih nekaj letih je bilo zgrajenih tudi več predorov, skozi katere je speljan tranzitni promet mimo večjih mest. Takšni predori so predor Plabutsch (10 km) v Gradcu, predor Pfänder (7 km) v Bregenzu in predor Schmitten (5,1) v Zell am Seeju, ki je trenutno v gradnji.

Medtem ko se na prostem škodljive snovi v izpušnih plinih vozil v zadostni meri mešajo s svežim zrakom, v predorih ni tako. Še posebej pomembno je zmanjševanje koncentracij zelo strupenega ogljikovega monoksida (CO) in črnega dima, ki zmanjšuje vidljivost v predoru, s svežim zrakom. Zaradi tega morajo biti cestni predori opremljeni z mehanskimi prezračevalnimi napravami. Poraba energije za pogon teh naprav je lahko zelo velika. Odvisna je od vrste predora (enocevni z dvosmernim prometom ali dvocevni z enosmernim prometom), sistema prezračevanja (vzdolžno, polprečno in prečno prezračevanje), gostote prometa (osebna in tovorna vozila) in dolžine predora [1]. V članku je podrobneje obdelana problematika porabe energije v cestnih predorih.

0 INTRODUCTION

You certainly know that Austria is a very mountainous country. Alpine road connections which can also be used during the winter require the building of long road tunnels. Therefore, it is not surprising that the first long Alpine tunnels were built more than 20 years ago, like the Katschberg tunnel (5.2 km), the Radstädter Tauern tunnel (6.4 km), the Gleinalm tunnel (8 km), the Arlberg tunnel (13 km), etc. Meanwhile, the Karavanke tunnel (7.8 km) which connects Austria and Slovenia has been completed. During the last few years, long by-pass tunnels were built around cities to keep the through - traffic away from the centers of population. Examples are the Plabutsch tunnel (10 km) in Graz, the Pfänder tunnel (7 km) in Bregenz and the Schmitten tunnel (5.1 km) in Zell am See, which is currently under construction.

While in the free atmosphere vehicle pollutants mingle sufficiently with fresh air, this is not the case in road tunnels. It is especially important to reduce the concentration of the quick-acting respiratory poison CO and the black smoke which reduces visibility in the tunnel (similar to outdoor mist) with the help of fresh air. A road tunnel therefore needs to be equipped with mechanical ventilation facilities. Power consumption for these facilities can be very high. It depends on the type of tunnel (one tube with two-way traffic or two tubes with one - way traffic), the type of ventilation (longitudinal ventilation, semi-transverse ventilation, transverse ventilation), traffic density (cars and trucks) and tunnel length. [1] The present study deals more closely with the power consumption in road tunnels.

Skupno porabo energije sestavlja dva glavna dela: energija za pogon prezračevalnih naprav ter energija za razsvetljavo predora in delovanje vseh potrebnih dodatnih naprav. V splošnem velja, da je poraba energije za pogon prezračevalnih naprav veliko večja od porabe vseh drugih naprav. Zato je prispevek posvečen porabi energije za pogon mehanskih prezračevalnih sistemov.

1 ENOSMERNI ALI DVOSMERNI PROMET V PREDORU

Pri načrtovanju avtocestnega predora, ki ni predolg, se pojavi vprašanje, ali zgraditi samo eno predorskou cev za promet v obeh smereh ali pa zgraditi dve ločeni cevi z enosmernim prometom v vsaki. Na prvi pogled se morda zdi, da so pri prvi izvedbi nižji tako stroški izgradnje kakor tudi obratovalni stroški prezračevalnega sistema. Vendar pa podrobnejša raziskava pokaže, da so obratovalni stroški prezračevalnega sistema v veliki meri odvisni od tega, ali je promet v predoru enosmeren ali dvosmeren [2].

Vsako vozilo, ki pelje skozi predor, učinkuje kot bat v dolgi cevi; pred seboj ustvarja nadtlak, za seboj pa podtlak. Tako se ustvari sila, ki premika zrak v predoru. Prostornina zračnega toka, ki tako nastane, je v veliki meri odvisna od vrste vozila (osebno ali tovorno), hitrosti vozil, geometrijskih oblik (razmerje vozilo/predor) ter od aerodinamičnih lastnosti predora in vozil.

V predoru z dvosmernim prometom eno vozilo ustvari potisno silo v eni smeri, nasproti vozeče vozilo pa enako veliko potisno silo, ki deluje v nasprotni smeri. Tako se v primeru enako gostega prometa v obeh smereh potisne sile, ki jih ustvarjajo vozila, med seboj uničijo. (Pri nesimetričnih ali mirujočih prometnih razmerah se lahko pojavi trenutna potisna sila v eni ali drugi smeri tudi v primeru dvosmernega prometa v predoru).

Razmere pa se spremenijo v primeru enosmernega prometa. Potisne sile, ki jih ustvarjajo posamezna vozila, se seštevajo in ustvarijo veliko potisno silo, ki potiska onesnažen zrak iz predora in hkrati sesa svež zrak v predor.

Pri dvosmernem prometu v predoru mora torej prezračevalni sistem dojavati potreben svež zrak v predor. Za to je potrebno veliko energije in vzdrževalec mora plačevati temu primerne stroške prezračevanja. Če je promet enosmeren, vozila sama v veliki meri poskrbijo za dovod svežega zraka in v bistvu vozniki sami pokrijejo večji del stroškov prezračevanja.

Zaradi tega, kot tudi zaradi večje varnosti uporabnikov predora v primeru požara, bi morali biti avtocestni predori zgrajeni iz dveh cevi, kadar je to le mogoče. Obe cevi sta lahko v takem primeru opremljeni z vzdolžnim prezračevalnim

The total power consumption is made up of two main parts: the required energy for the ventilation system on the one hand, and the power consumption of the lighting installation with all the other necessary accessory units on the other hand. Basically it can be said that the power consumption of the mechanical ventilation in a long road tunnel is much higher than the total energy required for all the other power-using devices. Therefore the study will only deal with the power consumption of the mechanical ventilation system.

1 ONE WAY OR TWO WAY TRAFFIC IN TUNNEL

When a highway tunnel is planned which is not too long, the question arises of whether to build just one tube to handle traffic in both directions or whether to build two tubes and have one-way traffic in each. At first it would appear that both construction and operation costs of the ventilation system would be lower for one tube than for two. A closer examination, however, shows that the operation costs for the ventilation system are in large part determined by whether there is one-way or two-way traffic in the tunnel [2].

Each vehicle which drives through the tunnel acts like a piston in a long pipe; there is excess pressure in front of the vehicle and low pressure behind. Thus a force is created which moves the air in the tunnel. The volume of the current of air which is produced in this way depends greatly on the vehicle (car or truck) driving speed, geometric conditions (atra rate vehicle/tunnel) and upon the aerodynamic features of the tunnel or vehicles.

In a tunnel with two-way traffic, one vehicle will create a thrust in one direction, the on-coming vehicle an equally large thrust in the opposite direction. Thus, with an equal amount of traffic in both directions, the total thrust cancels itself out. (Under asymmetric or stationary traffic conditions, there can be a brief thrust of air in either direction even when there is two-way traffic).

Conditions are entirely different for one-way traffic. The individual vehicle thrusts add up to a large thrust which propels the exhaust air out of the tunnel and sucks in fresh air.

Thus when a tube must cope with two-way traffic, the ventilation system must push the fresh air needed into the tunnel. This needs a lot of energy. The operators of the tunnel must pay the ventilation costs. When there are two tubes with one-way traffic, the vehicles themselves bring much of the fresh air into the tunnel. The ventilation costs in this case are met by the drivers.

For this reason as well as for the sake of the tunnel users' safety in the case of a fire, a highway tunnel should be built with two tubes whenever possible. Both tubes can then be equipped with a longitudinal ventilation system which is much cheaper. In this case, the construction expenses are also very low since there is no need for rock cutting in order to install air ducts, and the cross section can be designed in consideration of rock mechanics only.

sistemom, ki je veliko cenejši. V tem primeru so nižji tudi stroški izgradnje predora, saj ni potrebno dodatno vrtanje zaradi namestitve prezračevalnih cevi, prav tako pa je prerez predora mogoče načrtovati le z upoštevanjem mehanike kamenin.

Vendar pa so pri zelo dolgih dvocevnih predorih stroški vrtanja obeh cevi tako veliki, da je v večini primerov zaradi finančnih razlogov nemogoče zgraditi obe cevi hkrati.

Če je v prvi fazi zgrajena samo ena cev, mora biti ta opremljena z dražjim prezračevalnim sistemom (polprečnim ali prečnim), saj bo do izgradnje druge cevi v njej potekal dvosmerni promet. Drag prezračevalni sistem s prezračevalnimi cevmi velikih pretegov terja velik presek izvrtnane predorske cevi, prav tako pa so za prvo cev višji obratovalni stroški kakor za drugo, ki je lahko opremljena z vzdolžnim prezračevalnim sistemom.

2 PREZRAČEVALNI SISTEM IN STROŠKI ZA ENERGIJO PREDORA PLABUTSCH

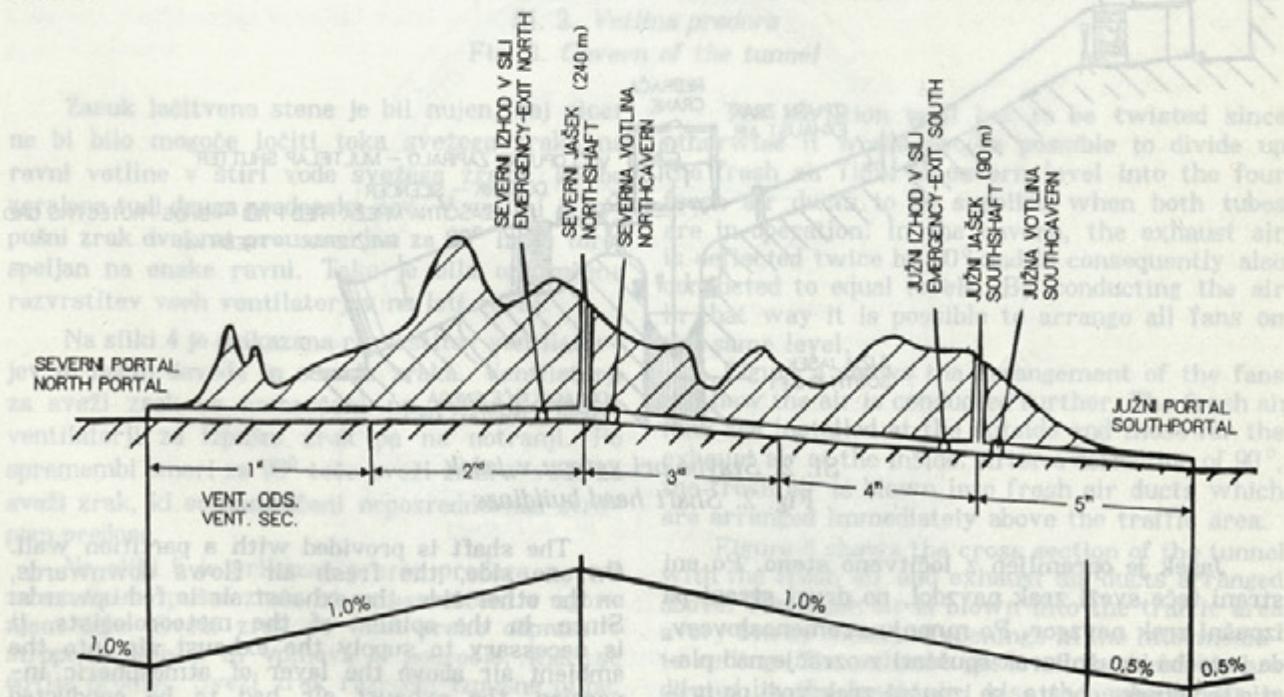
Predor Plabutsch je bil načrtovan kot dvocevni predor z enosmernim prometom v vsaki cevi. Vendar pa je bila v prvi fazi zgrajena le ena cev, v kateri trenutno poteka dvosmerni promet. Zato je v njej uporabljen prečni prezračevalni sistem s petimi prezračevalnimi odseki in dvema jaškoma [3], [4].

If very long two-tube tunnels are to be constructed, the costs for rock cutting for both tubes are so high that, for financial reasons, in most cases it will not be possible to build both tubes at the same time.

If only one tube is built at the beginning, the tunnel must be equipped with a costlier ventilation system (semi-transverse or transverse ventilation) since there is hardly any self-ventilating effect in the case of two-way traffic. The costly ventilation system with large-size air ducts requires large rock-cutting cross sections so that the construction and operating expenses for the first tube are higher than for a second tube which can be equipped with a longitudinal ventilation.

2 VENTILATION SYSTEM AND ENERGY COSTS OF THE PLABUTSCH TUNNEL

The Plabutsch tunnel is planned to have two tubes when completed, both tubes being operated in one-way traffic. At first, however, only one tube was built which also must take up the oncoming traffic. For the first tube, a transverse ventilation with five ventilation sections and two shafts was chosen [3], [4].



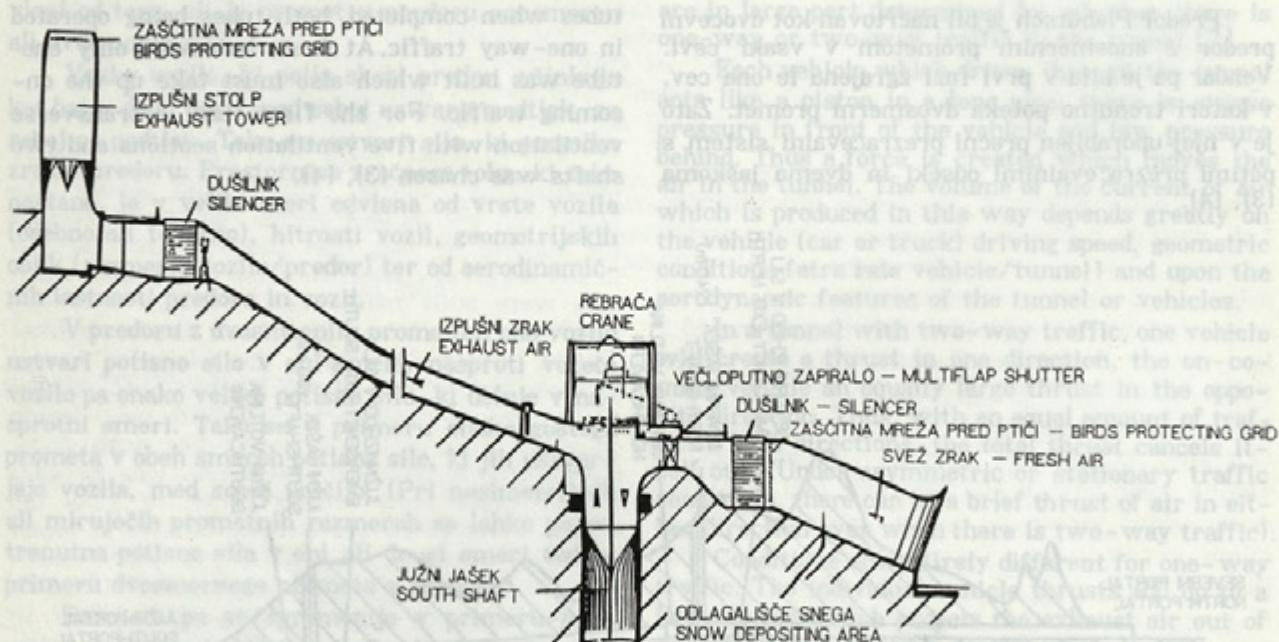
Sl. 1. Vzdolžni prerez predora
Fig. 1. Longitudinal section of the tunnel

Slika 1 prikazuje vzdolžni prerez predora s petimi prezračevalnimi odseki in dvema jaškoma. Dovajanje svežega zraka in odvajanje onesnaženega zraka v prvem odseku poteka prek severnega vhoda. Severni jašek, ki je dolg 90 m, oskrbuje drugi

Figure 1 shows the longitudinal section of the tunnel with its five ventilation sections and the two shafts. Aeration and de-aeration of the northernmost ventilation section (1st ventilation section) is carried out via the north portal. The 90 m high north shaft supplies the 2nd and 3rd

in tretji prezračevalni odsek, medtem ko 240 m dolg južni jašek oskrbuje četrti in peti prezračevalni odsek. Predor se od severnega vhoda vzpenja z nagibom 1%, nato se pa v drugem delu z enakim nagibom spušča, dokler ne doseže pokritega izkopanega dela, kjer se zmanjša na 0,5%.

Sveži zrak, ki se dovaja v predor prek južnega jaška, se zajema približno 90 m nad predorom. Nato se zrak dovaja v prostor za odlaganje snega, kjer je hitrost zraka zelo majhna, kakor je prikazano na sliki 2. Ob sneženju se v ta prostor odlaga sneg. Dušilnik zvoka, nameščen za prostorom za odlaganje snega, uduši velik del hrupa, ki ga povzročajo ventilatorji v votlini. Dušilnika zvoka je bilo treba namestiti zato, ker je območje, ki obdaja jašek, del rekreacijskega centra v neposredni bližini Gradca. Dušilniku sledita večloputno zapiralo in koleno, ki usmeri tok zraka v jašek. V zgornjem delu jaška je izpeljan tudi prehod iz pravokotnega prereza v okroglega.



Sl. 2. Stavbe pri vstopu v jašek

Fig. 2. Shaft head buildings

Jašek je opremljen z ločitveno steno. Po eni strani teče sveži zrak navzdol, po drugi strani pa izpušni zrak navzgor. Po mnenju vremenoslovcev, da je treba izpušni zrak spuščati v ozračje nad plastijsko topotnega obrata, se izpušni zrak vodi po približno 200 m dolgi cevi po bregu navzgor, v ozračje pa se spušča na vrhu približno 30 m visokega izpušnega stolpa. Zaradi zadostitve predpisom v zvezi s hrupom je tudi sistem za izpust zraka opremljen z dušilnikom zvoka. Nad jaškom je nameščeno tudi dvigalo, ki omogoča dviganje in spuščanje delovnega odra po delu za dovod svežega zraka in po delu za odvajanje izpušnega zraka.

ventilation section, while the 240 m high sout shaft supplies the 4th and 5th ventilation section. The tunnel ascends from north to south with a gradient of 1%, but then it descends again with a gradient of 1% until it reaches the »cut and cover« section which has a gradient of only 0.5%.

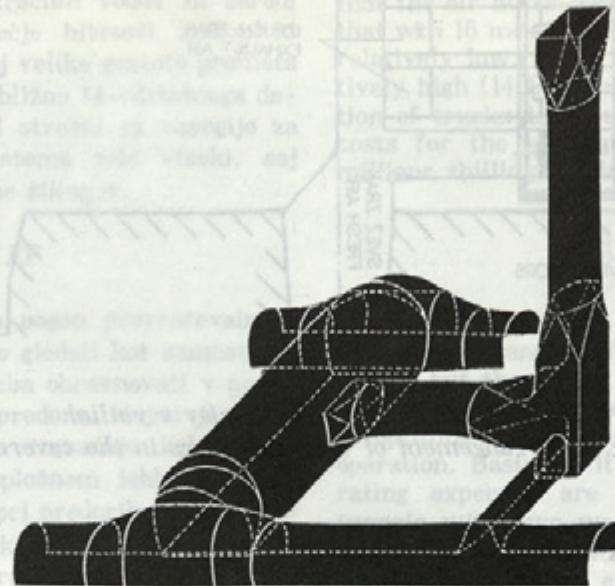
The fresh air required for the ventilation sections which are supplied by the south shaft is taken in from a level of approximately 90 m above the tunnel and is fed to a so-called snow depositing area where the air velocity is very low, as shown in figure 2. In case of snowfall the snow settles in this area. A silencer is installed behind the snow depositing area which absorbs a great deal of the noise caused by the fans arranged in the cavern. It was necessary to install the silencer since the area surrounding the shaft is part of the recreation centres in the immediate vicinity of Graz. The silencer is followed by a multiflap shutter and the deflection into the shaft as well as the transition from the rectangular cross section to the circular part of the shaft.

The shaft is provided with a partition wall. On one side, the fresh air flows downwards, on the other side, the exhaust air is fed upwards. Since, in the opinion of the meteorologists, it is necessary to supply the exhaust air into the ambient air above the layer of atmospheric inversion, the exhaust air had to be conducted onto a mountain slope by means of a duct of approximately 200 m length and discharged into the atmosphere out of a tower with a height of approximately 30 m. In order to meet with the noise reduction requirements, a silencer had to be installed in the exhaust air duct as well. A crane is situated immediately above the shaft. In case of need, this crane allows to let down a working platform as far as to the tunnel level both in the fresh air and in the exhaust air part.

Ločitvena stena v jašku ustvarja navpično ravnilo nad celotnim področjem jaška, ki je vzpopredna obema osema predora. V galeriji valjaste oblike med votlino in jaškom (sl. 3) je ločitvena stena, zasukana za 90° , tako da je pred votlino del za dovod svežega zraka v spodnji polovici galerije, medtem ko je del za odvod izpušnega zraka v zgornji polovici.

Strukturov analizje za posamezne sisteme predora ne smemo glestiti kot dejavnik, ampak jih je treba obravnavati znotraj stroških izgradnje predstavljajočih optimizirati tako stroškovane odprtine, ki jih stroški obrazujejo. V spletu pa je potreben da se obrazovalni stroški pri sistemom prometom vedno velikim presegajo z enosmernim pristopom.

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Sl. 3. Votlina predora
Fig. 3. Cavern of the tunnel

Zasuk ločitvene stene je bil nujen, saj sicer ne bi bilo mogoče ločiti toka svežega zraka na ravni votline v štiri vode svežega zraka, ko bo zgrajena tudi druga predorska cev. V votlini je izpušni zrak dvakrat preusmerjen za 90° in je torej speljan na enake ravni. Tako je bila omogočena razvrstitev vseh ventilatorjev na isti ravni.

Na sliki 4 je prikazana razvrstitev ventilatorjev in način dovoda in odvoda zraka. Ventilatorji za sveži zrak so nameščeni na zunanj strani, ventilatorji za izpušni zrak pa na notranji. Po sprememb smeri za 90° teče sveži zrak v vode za sveži zrak, ki so nameščeni neposredno nad stropom predora.

Na sliki 5 je prikazan rezrez predora z vodi za sveži in izpušni zrak, ki so nameščeni v zgornjem delu. Sveži zrak se nato preko odprtin v stropu vsakih 6 m vpihava v področje, kjer se odvija promet. Sveži zrak razredči izpušne pline. Izpušni plini se tudi odvajajo prek odprtin v stropu, ki pa so nameščene le na vsakih 12 m. Izpušne pline sesajo izpušni ventilatorji, v ozračje pa se odvajajo po jašku.

Dovajanje svežega in odvajanje izpušnega zraka v drugem in tretjem prezračevalnem oddelu poteka po severnem jašku. V načelu je delovanje enako kakor pri južnem jašku, zato ta del ni podrobno opisan.

ANALIZA VZD. MOCNIN

The partition wall between the fresh air and the exhaust air ducts form a vertical plane over the whole shaft area in parallel to the two tunnel axes. In the cylindrical gallery which is arranged between the cavern and the shaft (fig. 3), this partition wall is twisted by 90° so that before the cavern the fresh air section is situated in the lower half of the gallery, whereas the exhaust air section is the upper half.



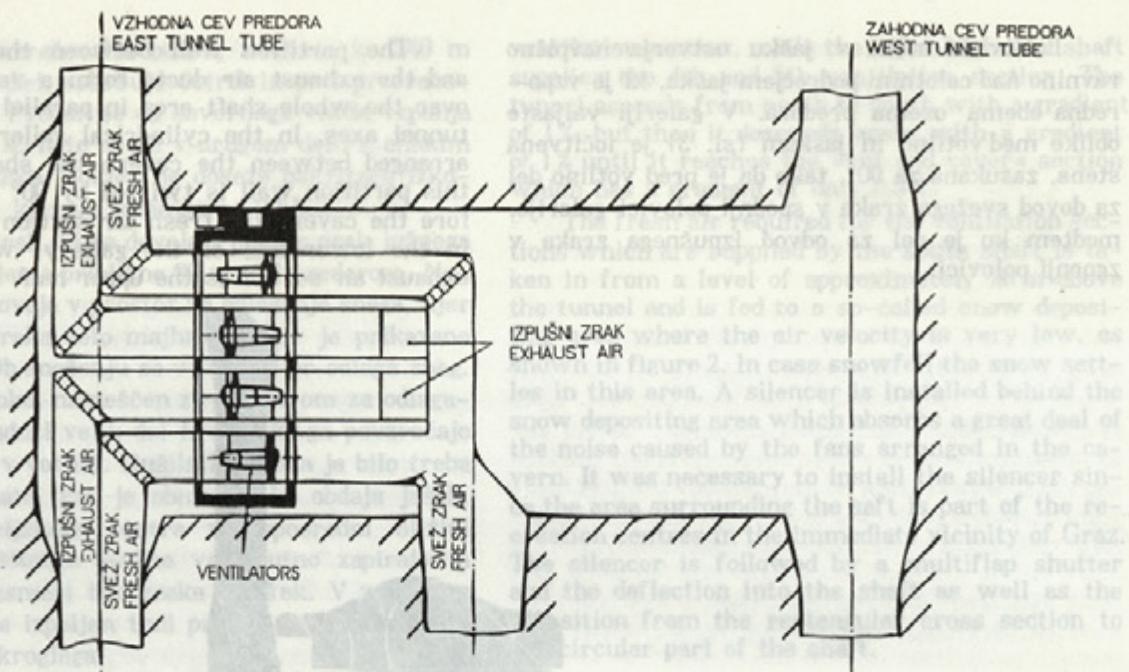
Sl. 4. Razvrstitev ventilatorjev
Fig. 4. Arrangement of fans

The partition wall has to be twisted since otherwise it would not be possible to divide up the fresh air flow at cavern level into the four fresh air ducts to be supplied when both tubes are in operation. In the cavern, the exhaust air is deflected twice by 90° and is consequently also conducted to equal levels. By conducting the air in that way it is possible to arrange all fans on the same level.

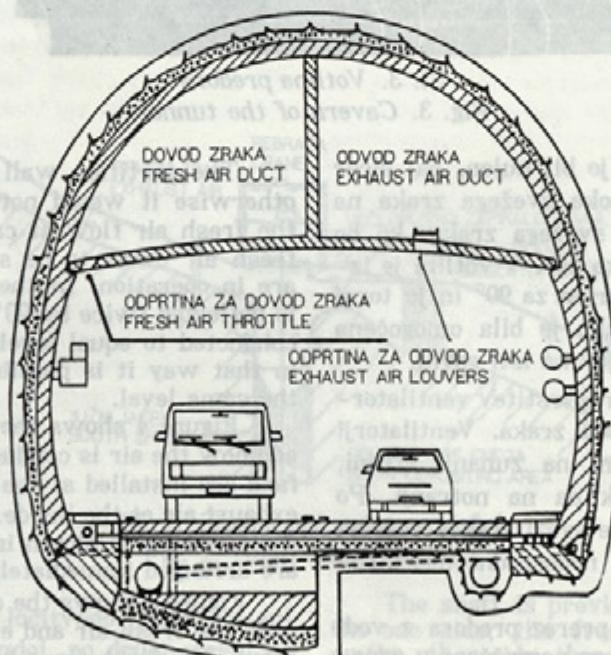
Figure 4 shows the arrangement of the fans and how the air is conducted further. The fresh air fans are installed at the outside and those for the exhaust air at the inside. After a deflection of 90° , the fresh air is blown into fresh air ducts which are arranged immediately above the traffic area.

Figure 5 shows the cross section of the tunnel with the fresh air and exhaust air ducts arranged above. The fresh air is blown into the traffic area every 6m by means of openings in the intermediate ceiling. The exhaust gases of the vehicles are diluted by the fresh air. Also the exhaust air is extracted by means of openings in the ceiling which, however, are arranged every 12m only. The exhaust air is sucked in by the exhaust fans and blown into the atmosphere via the shaft.

Aeration and de-aeration of the central ventilation sections is carried out via the north shaft. The air is conducted basically in the same way as described for the south shaft. It is not necessary, therefore, to consider it in detail.



Sl. 4. Razvrstitev ventilatorjev v votlini
Fig. 4. Arrangement of the ventilators in the cavern



Sl. 5. Prerez predora
Fig. 5. Tunnel cross section

Za prezračevanje najsevernejšega dela predora skrbi prezračevalna postaja zunaj predora. Sveži zrak se tudi tukaj dovaja preko področja za odlaganje snega in dušilnika zvoka, po dveh spremembah smeri za 90° pa pride zrak do ventilatorja. Ventilator za sveži zrak nato potiska sveži zrak neposredno v vod za sveži zrak.

The fresh air and exhaust air fans for the northernmost section are arranged in a ventilation station outside the tunnel. The fresh air is taken in again via a snow depositing area, as well as a silencer, and is conducted to the ventilator after two 90° deflections. The fresh air fan then presses the fresh air directly into the fresh air duct.

Ventilator za izpušni plin črpa izpušni zrak iz območja prometa, v ozračje pa se ta zrak spušča po izpušnem stolpu. Za zmanjšanje hrupa imamo tudi tukaj nameščen dušilnik zvoka.

Skupna moč, potrebna za pogon desetih ventilatorjev (v vsakem prezračevalnem odseku je en ventilator za sveži in en ventilator za izpušni zrak) znaša približno 3000 kW. Ta moč je tako majhna zaradi velikega preseka zračnih vodov in zaradi razmeroma majhne največje hitrosti zraka, ki znaša 16 m/s. Zaradi dokaj velike gostote prometa (14000 vozil dnevno) in približno 14-odstotnega deleža tovornjakov, so letni stroški za energijo za pogon prezračevalnega sistema zelo visoki, saj znašajo približno 4 milijone šilingov.

3 SKLEP

Stroškov energije za pogon prezračevalnega sistema predora ne smemo gledati kot samostojen dejavnik, ampak jih je treba obravnavati v povezavi s stroški izgradnje predora. Nujno je treba optimizirati tako stroške izgradnje kakor tudi stroške obratovanja. V splošnem lahko rečemo, da so obratovalni stroški pri predorih z dvostršnim prometom vedno veliko višji od stroškov pri predorih z enosmernim prometom, saj v drugem primeru vozila sama v veliki meri pripomorejo k prezračevanju.

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The exhaust air fans extract the exhaust air from the traffic section and the exhaust air is blown into the atmosphere via an exhaust tower. A silencer is installed also in the exhaust air duct in order to absorb the noise.

The total power required for the ten fans (there is one fresh air and one exhaust air fan for each ventilation section) is approximately 3000 kW. The reason why this figure is so low is that the air ducts have a large cross section and that with 16 m/s, the maximum air velocities are relatively low. Since the traffic density is relatively high (14000 vehicles per day) and the portion of trucks is around 14%, the yearly energy costs for the ventilation system are approx. 4 millions shillings which is very high.

3 SUMMARY

The energy costs for the ventilation system of a tunnel cannot be viewed as a stand-alone-factor, but they must be regarded in connection with the construction expenses. It is necessary to optimize both the costs for construction and operation. Basically it can be said that the operating expenses are always much higher for tunnels with two-way traffic than for tunnels with one-way traffic, since in the second case the self-ventilating effect can make itself felt to the full.

4 LITERATURA

4 REFERENCES

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