

# Dust in railway tunnels: Causes, Risks and Counter-measures

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Dust caused by trains results from friction processes (braking, wheel-track contact and power intake). The influence of dust entering rail tunnels becomes an ever-growing problem during their operation. Dust of this nature can lead to health problems for the maintenance and cleaning staff and endanger electronic components of switching and operating installations on account of its electric conductivity. A high degree of cleaning is required through dust affecting underground stations, which also pollutes the displays and products of the commercial concourses of stations and stops. In keeping with the findings of recent years, avoiding the admission of dust will become increasingly more important for planning rail infrastructural projects in addition to safety, ventilation and the climate of stations and tunnels. On the basis of examples illustrating how an underground tram station belonging to the Wiener Linien and the Lötschberg Base Tunnel operate, findings are presented and counter-measures suggested.

## 1 Initial situation

### 1.1 Sources of railway dust and particle sizes

"Railway dust" refers to dust caused by friction in brakes, overhead wires and pantograph contacts as well as the contact between wheels and rails. Dust is classified according to particle size using the PM scale. For instance, PM10 stands for dust with particle diameters less than 10 µm; this is referred to as fine dust or fine particulate matter. This definition of fine dust goes back to the "National Air Quality Standard for Particulate Matter" (abbreviated to PM Standard) laid down by the United States EPA (Environmental Protection Agency). According to this standard, 50% of the dust indicated by "PM10" contains particles with an aerodynamic diameter of 10 µm. Particles of this size can be inhaled beyond the larynx and penetrate very deeply into the lungs. This makes them particularly injurious to health. A large number of scientific studies have shown that there is a correlation between the particle concentration in inhaled air and respiratory diseases, as well as cardiovascular diseases, cancer and mortality rates. Braking operations represent the most important source of dust, accounting for over 60% of the PM10 emissions (Table 1).

Source	PM10 emissions for rail traffic in Switzerland in 2004			Total
	Passenger traffic [t/a]	Goods traffic [t/a]		
Brakes	354	264	618	60%
Rails	90	49	139	14%
Wheels	82	160	242	24%
Overhead wires	20	5	25	2%
<b>Total</b>	<b>546</b>	<b>478</b>	<b>1,024</b>	<b>100%</b>
<b>Proportion</b>	<b>53%</b>	<b>47%</b>	<b>100%</b>	

Table 1 PM10 emissions for rail traffic in Switzerland (from [2])



1 Railway station with glass façade

### 1.2 Special characteristics of fine particulate matter

Mass concentration level measurements in a cross passage of the Lötschberg base tunnel yielded values of 128 to 455  $\mu\text{g}/\text{m}^3$  depending on the time of measurement [1]. Fine particulate matter is characterized by a low deposition rate (1 to 2 cm/s). It may be assumed that at peak traffic times in the tunnel tube, when movements of air are very frequent (for instance in the cross passages), not only does additional dust get transported into the cross passages, but previously deposited dust is disturbed. Therefore measurements performed in cross passages are of only limited use in determining conditions in the traffic zone.

Measurement of particle size distribution showed that there is a relatively uniform distribution of the total mass throughout the size classes 0.3 to 1, 1 to 3 and 3 to 10  $\mu\text{m}$ . This means that there are more small particles than large ones. The railway dust under investigation proved to be highly magnetic and had a high iron and carbon content.

### 1.3 Situations which lead to especially high production / accumulation of dust

In view of the fact that braking operations account for most railway dust generation, the following situations are of particular significance:

#### Tunnel gradients

During descents the tendency to accelerate increases. Braking is necessary to avoid exceeding permitted speed limits. Slippage occurs during braking and accelerating operations whenever the maximum possible frictional force between the wheels and rails is exceeded. Depending on the tunnel gradient, braking operations may be necessary throughout the entire length of the tunnel. Furthermore, modern rolling stock is frequently capable of overcoming steep gradients. For instance, these days it is no longer unusual to include steep gradients of up to 80 ‰ for adhesion railways in the planning phase.

#### Halts

Braking and acceleration operations during the approach to and departure from halts release large amounts of dust. This also applies when the vehicle stops outside a tunnel but starts braking within it.

#### Tunnel system

In single-track tunnels the "piston-rod" effect accelerates the column of air in the direction of travel; the tunnel is ventilated by the traffic itself. Where the direction of travel alternates and in double-track tunnels, persistent air flows in one direction do not occur. The column of air is accelerated in differing directions. Air that is polluted with railway dust remains in the tunnel.

#### Equipment rooms, cross passages

If tunnel air which is polluted by dust is used for the ventilation and air-conditioning of rooms or cross passages intended for works and maintenance, there is a risk of the dust accumulating.

### 1.4 Effects of railway dust

Railway dust in underground traffic systems can be problematic. Reasons for this include:

- Railway dust conducts electricity and endangers electronic components in switching cabinets, e.g. ones used for safety, signaling and telecommunication equipment. Even when housings are designed to be dustproof, dust can enter when the equipment is maintained or repaired.
- Railway dust / fine particulate matter can represent a health hazard for maintenance personnel.

- Railway dust enters the commercial levels of underground stations and soils goods.

Railway dust in underground stations necessitates frequent cleaning. For instance, in some stations glass surfaces have to be cleaned daily.

Operational experience gained in recent years suggests that the avoidance of dust will become an increasingly important factor in planning and operating underground railway systems, alongside matters such as safety, ventilation and the air-conditioning of stations and tunnels.



2 Access to an underground station from the hall and introduction of vapor (left-hand image) and moisture to bind particles of railway dust

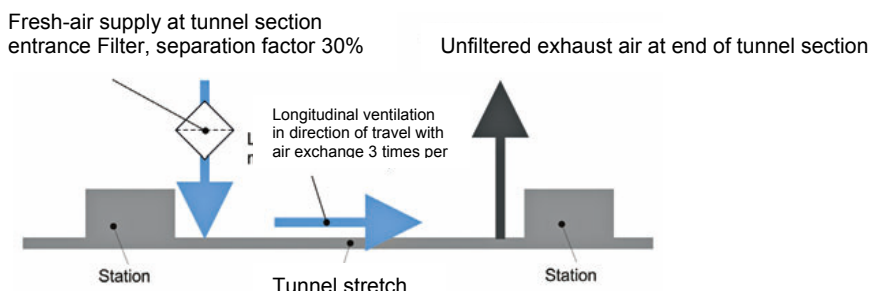
## 2 Operational experience

### 2.1 Example: underground station in Strasbourg railway station

Below the main railway station chosen here as an example (Figure 1) there is a double-track tram tunnel with an underground halt within the station building ( $l_{\text{tunnel}} = 1.6$  km, ascending on both sides of the halt with gradients up to 80 ‰). The station building was extended by means of a glass front. In this area of the covered station premises there are access ways to the underground halt (Figure 2, left).

The braking operations needed on approaching the halt generate large amounts of railway dust. As traffic travels in both directions, the dust-polluted air is not transported effectively towards a given portal. The dust concentration in the tram station accumulates, and then thermal effects and the "piston-rod" effect together cause dust to be transported into the roofed station precinct. As a result, wares on display and glass surfaces become soiled. In order to reduce the amount of dust caught up in the turbulence, and also to help bind it, water is sprayed at the tunnel entrances whenever a vehicle emerges (Figure 2).

The underground tram station is to be equipped with jet fans to generate longitudinal ventilation of the station towards the tunnel entrances. The jet-fan capacity is designed to ensure that on average a basic flow from the tram station towards the tunnel entrances is achieved. The supply air comes from the railway station precinct above as well as from the exits (outside air). Originally, the tunnel was intended to work as a ground-coupled heat exchanger. In summer, cooler tunnel air was to cool the station building, and in winter the tunnel air would warm it up. In view of the reversal of the flow direction in order to prevent dust accumulation, it may prove necessary to reappraise the station precinct air-conditioning concept.



### 3 Ventilation measures: Wiener Linien

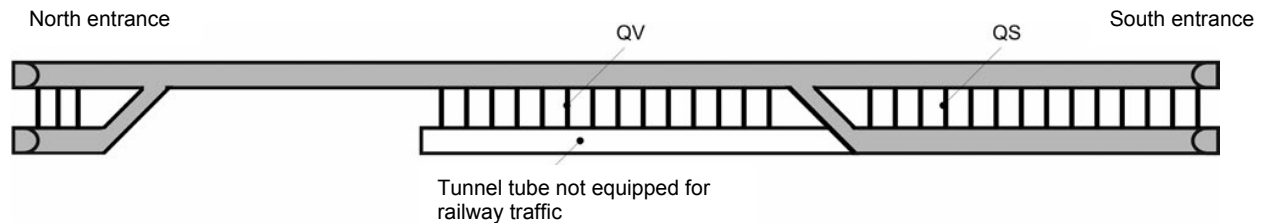
#### 2.2 Vienna underground railway system

The multi-layer underground railway network in Vienna consists of 5 routes (U1 to U4 and U6). The network is largely underground. The routes cross over in the stations on different levels, and are served every 3 to 5 minutes during the day. A large number of braking and acceleration operations leads to the introduction of large amounts of railway dust into the tunnels, stations and neighboring plant rooms. The rail and track cleaning is carried out by a mobile vacuum cleaner known as "Engelbert"<sup>1</sup>. In the suction section, the airflow is moistened with sprayed

<sup>1</sup> The oversized vacuum cleaner has the technical designation UGR11. The machine was named "Engelbert" after its developer.

water in order to bind the dust. This means that no dust is blown out of the upper part of the vehicle. In addition, the vehicle collects larger items such as drink cans and other waste from the track.

The entire 226 km of the Wiener Linien underground railway network are cleaned in accordance with a fortnightly rota, with certain stations and track stretches being treated weekly. Engelbert travels at up to 15 km/h in cleaning mode. In addition, longitudinal ventilation of the tunnels largely prevents the accumulation of railway dust. In an ideal case, filtered fresh air is introduced at the beginning of a tunnel stretch, and the air is extracted at the other end before the next station is reached (Figure 3). The volume of air involved depends on the length of the tunnel stretch, and it is replaced approximately 3 times per hour.



4 Overview of the Lötschberg base tunnel with characteristic single- and double-tube sections equipped for rail traffic

### 2.3 Example: Lötschberg base tunnel cross passage

The Lötschberg base tunnel was commissioned in December 2009 (Figure 4). With a total length of approx. 35 km, the tunnel connects Frutigen (northern entrance) with Raron (southern entrance). The tunnel has gradients of 3 ‰ and 13 ‰ from the highest point to the entrances. The tunnel is approved for speeds up to 250 km/h. The bridge over the Rhône near the southern entrance is only approved for 160 km/h. Trains travelling down the gradient brake frequently, either to compensate for the tendency to accelerate on account of the inclined plane forces acting, or in order to reduce speed to the permitted speed for exiting the tunnel.

Generally, railway dust generated by downhill travel is transported in the direction of travel on account of the "piston-rod" effect. Sometimes railway dust remains in the tunnel system because of the alternating timetable and thermal lifting forces or down forces. Spaced about 333 m apart, there are cross passages between the railway tunnel tubes or cross connections to the tunnel tube not equipped for rail traffic. There are vents above the doors at each end of each cross passage (Figure 5).

Depending on the timetable and traffic-induced pressure conditions, pressure differences arise between the tunnel tubes. The pressure differences between the tunnel tubes and the cross passages then equalize. Dust-laden air is introduced into the cross passages, and railway dust accumulates there. Figure 6 shows railway dust deposits on the switching cabinets in a cross passage. This can cause a problem when the cabinets are opened, because the electrically conductive railway dust can come into contact with the electrical components.

The cross passages / connections are cleaned approx. twice yearly. Figure 7 shows cleaning work being carried out: the floors are cleaned using a ride-on machine, whilst the switching cabinets are cleaned using a manual vacuum device. The cleaning staff wear special helmets; inhalation of dust-laden air is prevented by means of a fresh-air curtain under the helmet's visor.

## 3 Ways of preventing the introduction of dust

The various possible measures that can be taken to avoid railway dust in underground traffic systems depend very much on the local structural conditions (gradients, aerodynamic connection between sections etc.), the timetable and the rolling stock involved (Table 2). The following section contains a detailed discussion of the use of filters for the cross passages / connections in the Lötschberg base tunnel.

## 4 Investigations in the Lötschberg base tunnel

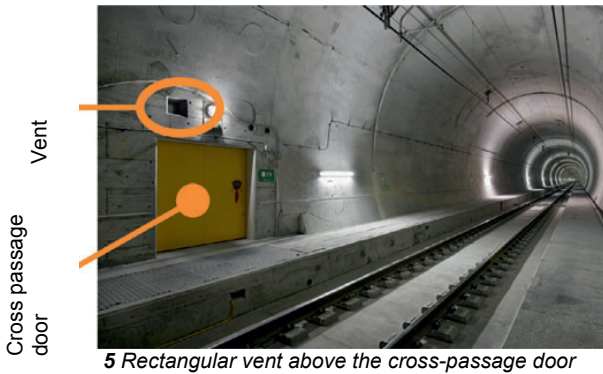
The next section describes the possible means of dust separation, and this is followed by extracts from the measurement results obtained.

### 4.1 Dust separation

Table 3 summarizes three different means of filtering air.

Textile filters are ring-shaped or rectangular, flat, paper-like units in which folded textile serves as the filtering agent. The zig-zag folding increases the filter surface and lowers the flow resistance, while at the same time increasing the unit lifetime. These filter inserts are disposed of after a single use.

As an alternative, large area air filters are commonly used. The filter element is a flat filter mat which is folded and fixed in a frame within an air-filter box. Generally, the air flows from below through the horizontally placed filter element. This means that when the air stream ceases, larger foreign bodies held back by the filter element fall to the bottom of the filter box and thus no longer represent a hindrance to the flow of air. Paper-based air filters are simple and economical to produce.



5 Rectangular vent above the cross-passage door



6 Soiling of the outside of the dust-proof switching cabinets



7 Cleaning work in a cross passage of the Lötschberg base tunnel

Bag filters are often used for industrial purposes. Several filter tubes are stabilized by means of wire cages and hang vertically downwards. Dust becomes caked on their cylindrical exteriors. Such filters are cleaned either according to the degree of caking (pressure control) or after a given time has elapsed (time control).

Cyclonic filters are used in large industrial applications to separate off solid or liquid particles suspended in gases (e.g. for flue gas purification). In cyclonic filters the inherent flow speed of the gas is used together with the corresponding design of the device to induce a rotary movement. The particles are accelerated centrifugally, which separates them from the flow of gas. The gas is conducted inwards and drawn off. The effectiveness of a cyclonic filter is heavily dependent on the acceleration of the air. This means that a considerable amount of energy must be expended. Cyclonic filters are not very suitable for separating small particles.

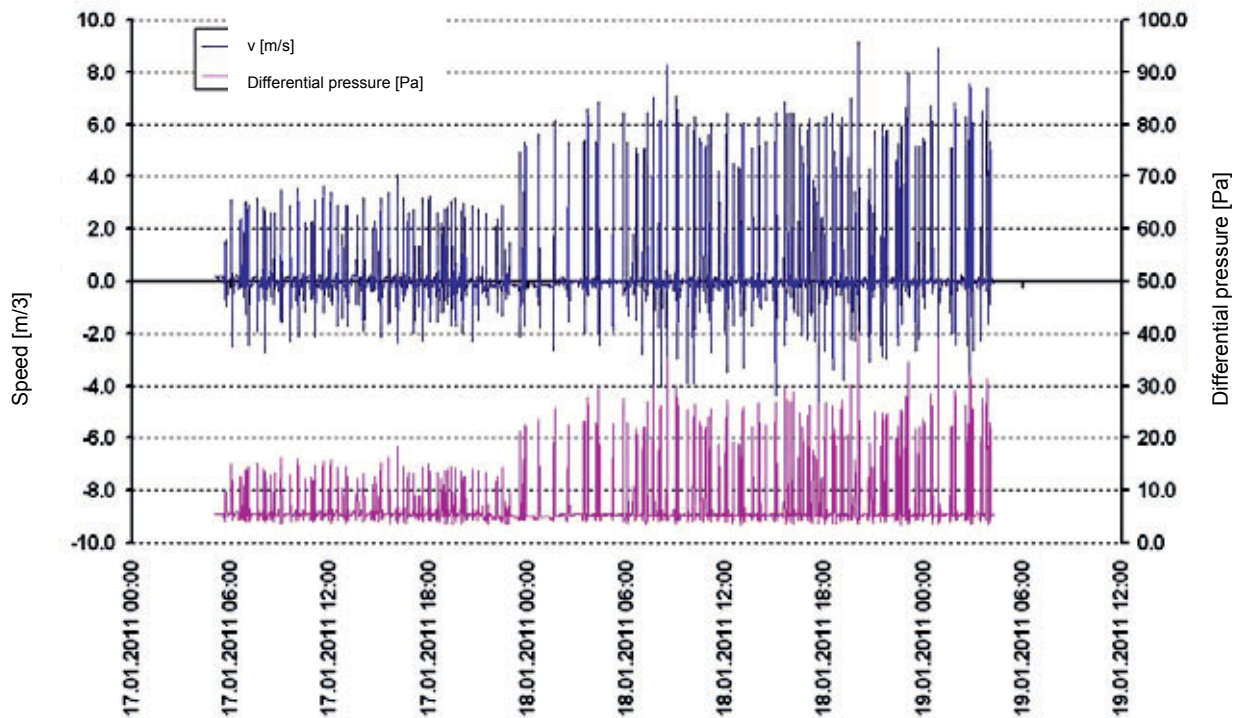
In electrostatic precipitators, dust particles are electrostatically charged and separated off on the electrode surfaces. The soiling is then removed either by means of "knocking off" or by rinsing at regular intervals. Electrostatic precipitators have the advantage of causing only a small drop in pressure, but they lack operational reliability. If the high-voltage supply fails, this usually means that large amounts of pollutant pass through unfiltered. Furthermore, if flow rates vary a great deal, dust which has collected on the surface may be swept away by a sudden increase in the flow. Another problem associated with electrostatic precipitators concerns the corona discharge caused by the high tension. This in turn has the effect of generating ozone (O<sub>3</sub>) from the oxygen in the air.

Measure/Effect	Possible advantages	Possible disadvantages
<ul style="list-style-type: none"> <li>filtering: through the use of filters the air polluted with railway dust is treated, e.g. for ventilation of equipment rooms and cross passages</li> </ul>	<ul style="list-style-type: none"> <li>operational longevity and reduced maintenance requirements</li> <li>easy and quick filter change</li> </ul>	<ul style="list-style-type: none"> <li>costs of filter equipment</li> <li>mechanical promotion of air supply may be needed</li> <li>dust remains in the system</li> </ul>
<ul style="list-style-type: none"> <li>push-pull ventilation: by supplying fresh air at the beginning of a tunnel section and extracting it at the end/flow direction in direction of travel (3 changes of air)</li> </ul>	<ul style="list-style-type: none"> <li>dust is extracted from the system</li> <li>ventilation systems are often present already</li> <li>tried and tested measure</li> <li>dust remaining in system is diluted by filtered supply air</li> </ul>	<ul style="list-style-type: none"> <li>High energy costs from permanent operation of axial fans</li> <li>reduced effectiveness if air is drawn off along the ventilation stretch, e.g. for ventilating equipment rooms</li> <li>inconvenience for passengers and neighbors (noise)</li> </ul>
<ul style="list-style-type: none"> <li>ongitudinal ventilation: longitudinal ventilation by means of jet fans</li> </ul>	<ul style="list-style-type: none"> <li>railway dust leaves system</li> <li>low investment and operating costs</li> </ul>	<ul style="list-style-type: none"> <li>inconvenience for passengers and neighbors (noise)</li> <li>reduced effectiveness if air is drawn off in the course of the ventilation section, e.g. for ventilating equipment rooms</li> <li>if air is resupplied via stations: station climate is affected</li> </ul>
<ul style="list-style-type: none"> <li>non-mechanical braking operations: use of eddy-current brakes and electromotive brakes (reverse motor function)</li> </ul>	<ul style="list-style-type: none"> <li>main source of railway dust is removed</li> <li>no acoustic effects</li> <li>no additional influence on movement of air advantageous in case of emergency</li> </ul>	<ul style="list-style-type: none"> <li>not all rolling stock suitably equipped</li> <li>with eddy-current brakes undesirable heating of rails</li> </ul>

Table 2 Measures available for reducing/avoiding railway dust

Separator	Separator effect	Advantages	Disadvantages
Textile filter	very good	simple, cheap	Temperature range, pressure loss, lifetime
Bag filter	very good	simple, cheap	Temperature range, pressure loss, lifetime
Cyclonic filter	insufficient	simple, robust	considerable technical effort needed; effectiveness depends on load
Electrostatic precipitator	good	low pressure loss, relatively robust	considerable technical effort needed; effectiveness depends on operating conditions
Wet separator	good	can be combined with adsorption/absorption reactions	complexity, pressure loss

Table 3 Comparative list of dust separators for use in railway tunnels



8 Exchange of air caused by traffic movement in a cross passage of the Lötschberg base tunnel before / after changing the cross-section of the non-return flap

#### 4.2 Practical test in Lötschberg base tunnel

Some of the filter variants described above have been or are being tested for practical serviceability in the Lötschberg base tunnel. A filter concept involving dry filters was recommended and implemented/installed in a cross passage. Initial tests produced very positive results, so that the decision was taken to extend the test to several cross passages. To ensure that the use of dry filters is successful, particular attention must be paid to the air-exchange mechanisms in the cross passages and the filter lifetimes.

#### 4.3 Exchange of air in the cross passages

The way air is exchanged in the cross passages and cross connections in the Lötschberg base tunnel plays a significant role. The surplus heat generated by the equipment in the cross passages and cross connections must be drawn off to prevent overheating. For the purposes of exchanging air and drawing off surplus heat from the cross passages, there are openings above the doors which allow movement of air as a result of the traffic-related pressure fluctuation.

Measurements of the air exchange frequency in a cross passage have shown that the pressure/suction effects produced by the trains cause large volumes of air to be moved in and out of the cross passage. The volumes are restricted by the cross-section of the opening, which, particularly in the cross passages, is greatly reduced by relatively small non-return flaps (150 mm diameter) (Figure 8). The retro-fitted non-return flaps ensure that that fresh air is introduced only from the ascending tube. Therefore the flap cross-section was increased in the course of the tests in order to achieve higher flow rates.

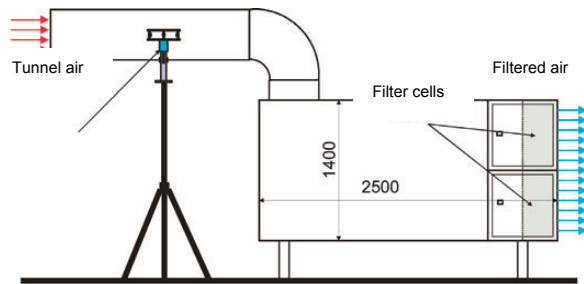
#### 4.4 Tests with a dry filter (textile filter)

The cross passage vent connecting with the ascending tunnel tube was provided with a filter. The vent connected with the descending tube is equipped with an excess-pressure flap, so that air can enter the tube from the cross passage, but no air can flow into the cross passage from the tube. The flow rate in the ventilation section as well as the pressure loss owing to the filter were measured. The loss in pressure is an indication of the degree of

clogging in the filter and therefore its lifetime. As it represents an important peripheral parameter, the temperature in the cross passage was measured as well.

Figure 9 shows a schematic representation of the testing arrangement (left) and on the right an image of the testing apparatus. An air duct is attached to the rectangular cross-passage vent with a cross-section equivalent to two filter cells. The filter box containing the two filter cells is long enough to ensure that the flow to the two filter cells is uniform. The flow volume through the vent into the cross passage or out of the cross passage is determined by means of a two-dimensional ultrasound anemometer.

The fine particulate matter filters used are of the same type as those used in air-conditioning systems for screening out fine dust. Folded filter cells corresponding to filter class 6 were used for the tests. These have a separation capacity which is sufficient for the main grain category occurring in the tunnel.



9 Filter box with measurement equipment used (flow measurements in round tube duct)

## 5 Measurement results

The measurements and subsequent calculations showed that by increasing the cross-section of the non-return flap the mean volume of air moved could be raised to approx. 350 m<sup>3</sup>/h. This is not sufficient for some cross passages in the Lötschberg base tunnel. In the cross passage under investigation, the temperature could be maintained at approx. 30 °C by this means. Accordingly, thermal equilibrium was reached in the cross passage (surplus heat from equipment + ambient heat = heat drawn off).

In view of the relatively small volumes of air (the nominal flow volume capacity of the filter cells is by no means reached), very little pressure is lost because of the filter. Therefore it is to be expected that with the prevailing airflow volumes the filters used will last for several years. In subsequent tests the air throughput is to be increased considerably. No measurement of the separation capacity was carried out, but the manufacturer guarantees certain separation values, so that it may be assumed that these were achieved.

## 6 Knowledge gained and recommendations for further measures

The investigations carried out in the Lötschberg base tunnel have shown that even after the installation of a filter a sufficient exchange of air takes place in the cross passage concerned and that the dry filter used can withstand the pressure stresses in the tunnel. A further criterion determining the usability of this method is that the filters be sufficiently durable.

As the flow volumes for some cross passages in the Lötschberg base tunnel can be expected to be too low to draw off all the heat generated, the following measures will be considered to increase the flow volumes:

- further widening of the free cross-section
- allowing exchange of air in both directions
- active promotion of the exchange of air by means of in-line fans

When it comes to standardizing the installation of filters in cross passages, improvements are possible, e.g.

- simple, robust construction
- economic use of materials
- easy access to filter
- easy handling/low maintenance requirement when changing filter
- simple monitoring of filter lifetimes

For instance, installation would be possible above the cross-passage door in the area of the ridge. In the cross passages where the train-related exchange of air is insufficient, mechanical ventilation, e.g. with the help of an in-line fan, will be necessary.

## 7 Conclusion

The generation of electrically conductive railway dust in underground traffic systems can necessitate the need for frequent cleaning and impair the availability/reliability of electromechanical equipment. Using examples from

different sources (underground station in Vienna, Lötschberg base tunnel), the local situations and the measures taken to improve them are illustrated.

More extensive investigations carried out in a cross passage of the Lötschberg base tunnel showed that a suitable filter can significantly reduce the amount of dust introduced into the cross passage. Further investigations are planned to verify the extent to which the results can be applied to other cross passages.

### 8 Acknowledgments

We would like to express our thanks to Hans Stadelmann and Daniel Suter of BLS AG for their friendly support and co-operation and for the exchange of information. Our thanks also go to Beat Brügger of Brügger-HTB GmbH for permission to use illustrative material as well as for sharing information.

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