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VENTILATION SYSTEMS OF TRANSPORT TUNNELS: CLASSIFICATION, STRUCTURE AND PRINCIPLES OF OPERATION

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Annotation. The article discusses the types of tunnels, the features of their ventilation and the equipment used. The main focus is on transport tunnels, where ventilation is necessary to ensure safe driving conditions and protection from harmful emissions. Two types of ventilation are described: natural, based on thermal pressure, and mechanical, which provides air supply and removal using fans. Axial and jet fans, their design, principles of operation and advantages are presented in detail. Ventilation schemes are considered: longitudinal, transverse and combined, each of which has its advantages and disadvantages. Special attention is paid to fire protection and smoke removal in case of fires. It is indicated that the choice of ventilation system affects the size and design of the tunnel, therefore it is determined at an early stage of design. The material may be useful for specialists in the field of construction and operation of underground transport facilities.
Keywords: Tunnel, ventilation, transport facilities, axial fans, jet fans, natural ventilation, mechanical ventilation, longitudinal ventilation, transverse ventilation

СИСТЕМЫ ВЕНТИЛЯЦИИ ТРАНСПОРТНЫХ ТОННЕЛЕЙ: КЛАССИФИКАЦИЯ, УСТРОЙСТВО И ПРИНЦИПЫ РАБОТЫ

Аннотация. В статье рассматриваются виды тоннелей, особенности их вентиляции и применяемое оборудование. Основное внимание уделяется транспортным тоннелям, где вентиляция необходима для обеспечения безопасных условий движения и защиты от вредных выбросов. Описаны два типа вентиляции: естественная, основанная на тепловом напоре, и механическая, обеспечивающая подачу и удаление воздуха с помощью вентиляторов. Подробно представлены осевые и струйные вентиляторы, их конструкция, принципы работы и преимущества. Рассматриваются схемы вентиляции: продольная, поперечная и комбинированная, каждая из которых имеет свои плюсы и недостатки. Особое внимание уделено противопожарной защите и удалению дыма при возникновении пожаров. Указано, что выбор системы вентиляции влияет на размеры и конструкцию тоннеля, поэтому определяется на раннем этапе проектирования. Материал может быть полезен для специалистов в области строительства и эксплуатации подземных транспортных сооружений.

Ключевые слова: Тоннель, вентиляция, транспортные сооружения, осевые вентиляторы, струйные вентиляторы, естественная вентиляция, механическая вентиляция, продольная вентиляция, поперечная вентиляция

Tunnel- this is an underground or mountain-like enclosed structure, usually built to provide for the movement of vehicles (cars, trains) or pedestrians.
All tunnels have several safety systems, one of which is the ventilation system.
The main tasks of ventilation in tunnels are:
– ensuring the necessary cleanliness and temperature, pressure, humidity, and air velocity in the tunnel;
– significant reduction of the content of harmful substances in the transport zone and in the air discharged from the tunnel at the locations of air outlets (ventilation corners);
– ensuring the rapid removal of combustion products, smoke removal, and assistance in evacuating people in the event of a fire;
– Preventing freezing of roads, tunnel equipment, and operational equipment in areas with cold climates.
Ventilation systems and equipment in large tunnels can account for up to 30% of their costs. Ventilation in transport tunnels is provided by natural or mechanical methods.
1. Natural ventilation of tunnels occurs under the influence of thermal pressure, which is created by the temperature difference between the tunnel and the outside air. Its effectiveness largely depends on the geographical and altitude conditions of the tunnel location, the length of the tunnel, as well as the number and volume of moving traffic, as well as other factors.
2. Mechanical ventilation of tunnels (artificial ventilation) is carried out by supplying fresh air through air exchange, removing polluted air, or simultaneously supplying clean and waste-free air. In tunnels up to 300 m long, natural ventilation is allowed, in tunnels longer than 300 m, the issue of ventilation is resolved before the design of tunnel structures, since the choice of ventilation system in most cases determines the dimensions of the tunnel section. Therefore, first the ventilation system is installed, the amount of air required for ventilation of the tunnel is calculated, the required cross-sectional area of the ventilation ducts is determined, and the cross-sectional dimensions of the tunnel are calculated. In addition, when designing the tunnel, it is necessary to provide for mechanical devices that will remove toxic smoke from the tunnel in the event of a fire. The parameters of the smoke exhaust system are also determined by calculation.
Free ventilation is ventilation in which air flow occurs without fans or mechanical means, due to the following physical phenomena:
1. Temperature difference - the difference in air temperature between the indoor and outdoor environment (especially noticeable in the winter season).
2. Wind pressure - the force of wind blowing through open openings.
3. Thermal convection - hot air rises and cold air sinks, creating a natural current.
The design air pressure in the tunnel is determined as the algebraic sum of all aerodynamic resistances created in the transport zone, longitudinal and transverse channels during air exchange and air distribution, as well as due to natural air draft. Additional data that must be taken into account in aerodynamic design: meteorological parameters, barometric pressure difference and wind. Artificial ventilation of tunnels involves the removal of all harmful gases and dust particles from the tunnel by artificially creating an air flow using mechanical fans.
Advantages:

- Low construction and operating costs.
- No electricity required.

- Maintenance is easy due to the simplicity of the system.

Disadvantages:

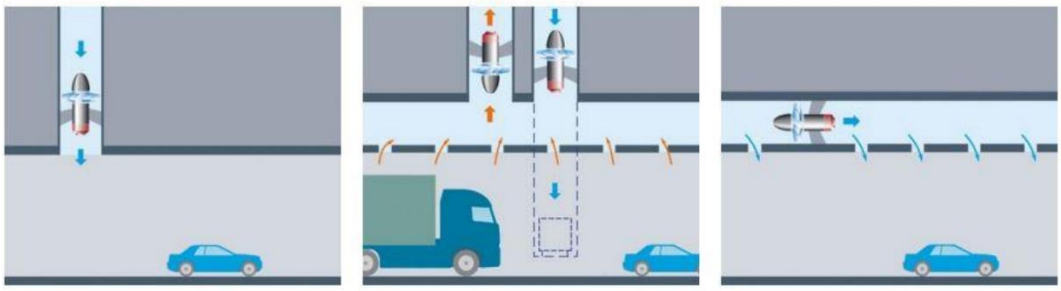
- Only effective under certain conditions (e.g., if there is a temperature difference).
- Long and action-packedNot enough for tunnels.
- Cannot quickly vent smoke in case of fire.

There are various types of ventilation systems in tunnel construction, designed to remove dust and toxic gases during its construction and operation. The main functions of ventilation systems in tunnels are:

- Providing a working environment with clean air.
- Ensuring fire safety.
- Elimination of exhaust gases.
- To prevent the accumulation of fuel and toxic gases and to eliminate the risk of explosion of these types of gases.

A fan is a mechanical device designed to supply air directly into an object or extract air from an object, as well as to circulate and move air through the air ducts of ventilation systems, creating the necessary pressure difference.

According to their design features and operating principle, fans are divided into axial (axial) and centrifugal fans. Also, according to the direction of rotation of the blades of the device (unidirectional or bidirectional) - the right and left sides rotate at the same speed.



Axial flow fans

Axial fans are the preferred technology for large volumes of air and are ideal for cross or semi-cross tunnel systems. They are also suitable for smoke collection. The advantages of axial fans can include:

- Low noise level during operation;
- High efficiency;
- Easy to operate;
- Low cost and simplicity of design;
- Low power consumption;
- Long service life;
- Protect the engine from overload, sparks, moisture;
- The ability to change the speed of rotation of the blades by changing the speed of the motor;

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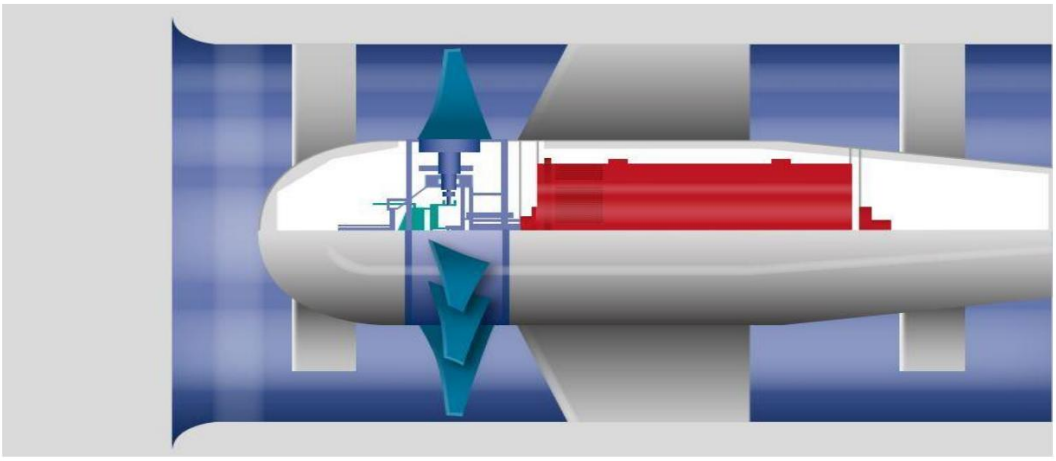


Axial fan structure

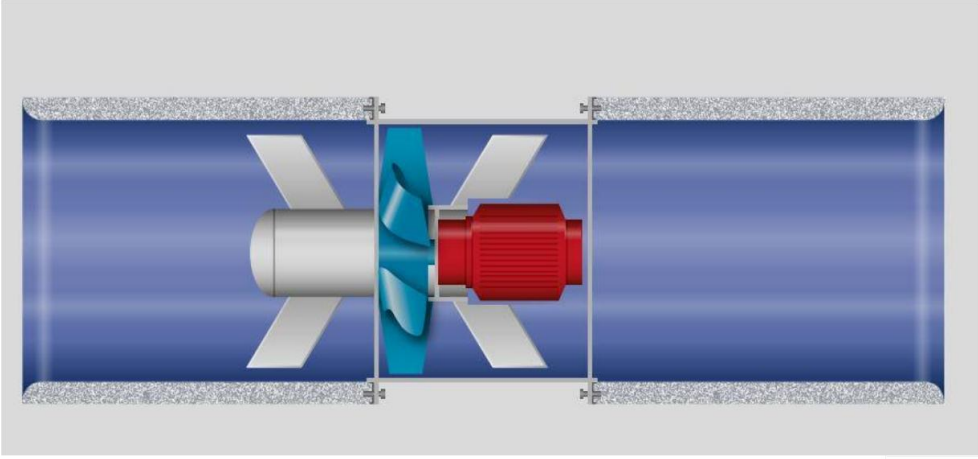
Centrifugal fan - This is a type of fan that draws air in from the center and exhausts it in a perpendicular direction (from the sides). Centrifugal fans are a cost-effective solution for forced ventilation and smoke extraction from enclosed, underground areas. The main purpose of centrifugal fans is to remove dust and toxic gases from a contaminated parking lot or smoke trapped in a fire zone by creating a high-velocity air flow. In other words, they help move air from the point of entry to the point of exhaust. Centrifugal fans are multifunctional: they serve both as conventional ventilation and as smoke extraction during a fire. This type of fan is very useful in tunnels with traffic in both directions or where the wind can significantly affect the air flow in the tunnel.

Advantages:

- Creates high pressure;
- It carries air over long distances;
- Resistant to dust and gaseous air;
- Reliable and durable.

Disadvantages:

- Takes up a lot of space;
- The noise level may be relatively high;
- High energy consumption (sometimes).



Centrifugal fans

In road and railway tunnels, which are an integral part of modern transport infrastructure, there is a great need for effective ventilation systems to ensure safety and a healthy environment. Especially when there is a need to quickly remove smoke, gas particles and heat, a mechanical ventilation system is recognized as the most optimal solution. Mechanical ventilation systems include longitudinal, transverse and mixed methods. According to their names and operating principles, they operate on the principles listed below and have a number of advantages and disadvantages, including:

Cross ventilation- This is a system that organizes air movement through the tunnel in a transverse direction (i.e., through inlets and outlets, in a cross-sectional manner). In this method, air is introduced from one side and expelled from the opposite side.

In this system, fresh air is supplied to the tunnel through inlet fans, and exhaust fans expel polluted air. In this way, the air flow is constantly renewed.

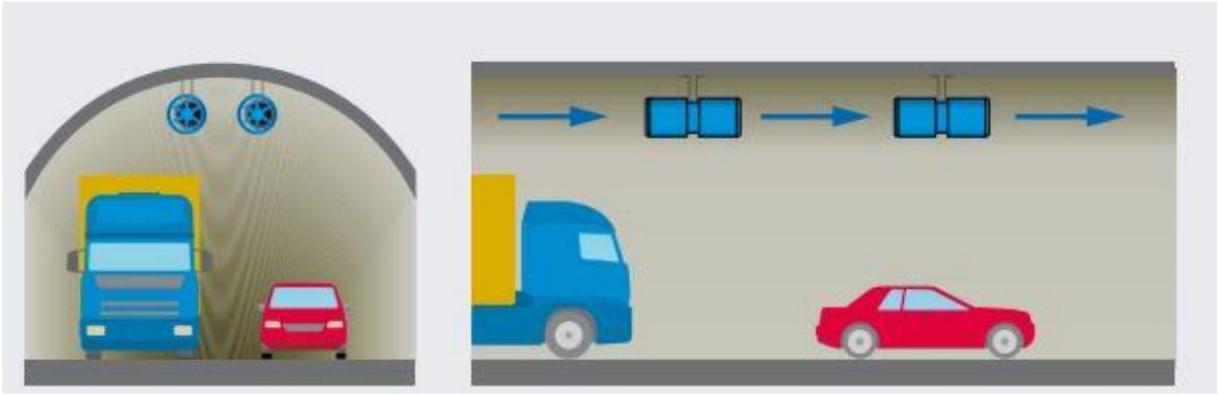
Advantages:

- Simple in structure: cheaper and easier to operate than other complex systems.
- Takes up little space: no large ducts or pipes required.
- Flexibility: Suitable for small to medium-length tunnels.

Disadvantages

- Ineffective for long tunnels: the air flow may not reach the end of the tunnel.
- The smoke may not be completely removed: especially if there is heavy traffic.
- Energy consumption may be high: in continuous operation.

The transverse ventilation system is characterized by its simplicity and low cost. It is an ideal solution, especially for short and medium-length tunnels. However, in long tunnels or in areas with high levels of gas and smoke, it should be used in conjunction with other systems (e.g. longitudinal or mixed ventilation).



Cross ventilation system

Longitudinal ventilation is a ventilation system that ensures the movement of air along the longitudinal direction of the tunnel (i.e. from the entrance to the exit). In this method, the air flow moves in the same direction as the road itself. Ventilation is carried out using jet fans.

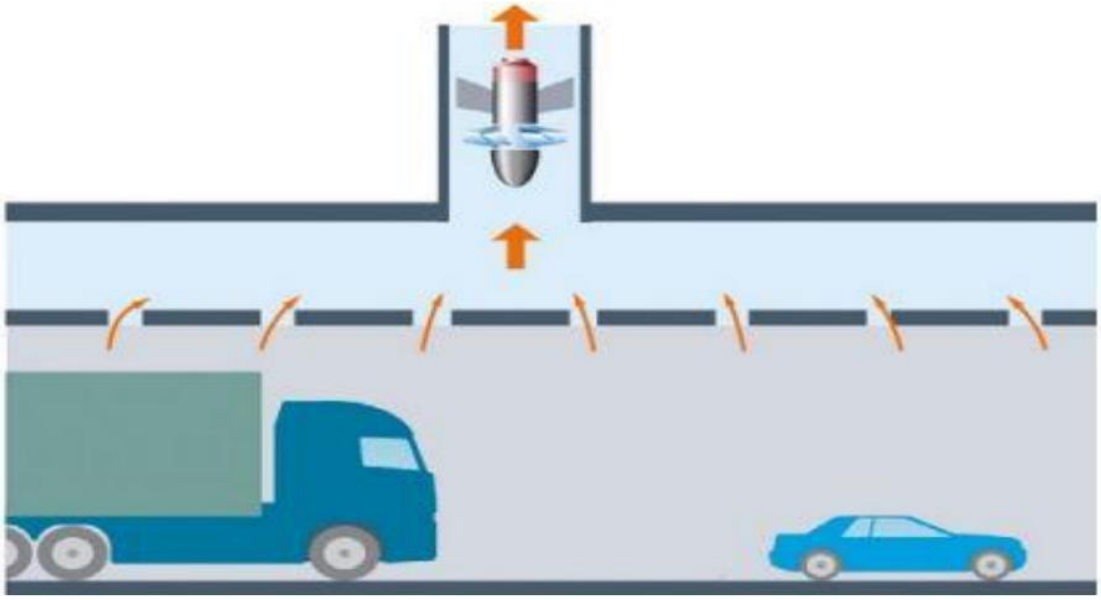
Jet fans are installed in the ceiling (upper part) of the tunnel and they move the air flow in the direction of traffic.

Working principle:

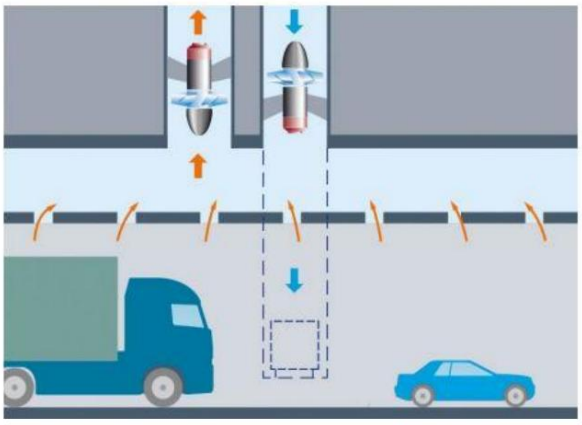
1. Sensors detect the amount of gas or smoke in the air.
2. Jet fans start automatically.
3. The air moves from the inlet to the outlet in a strong current.

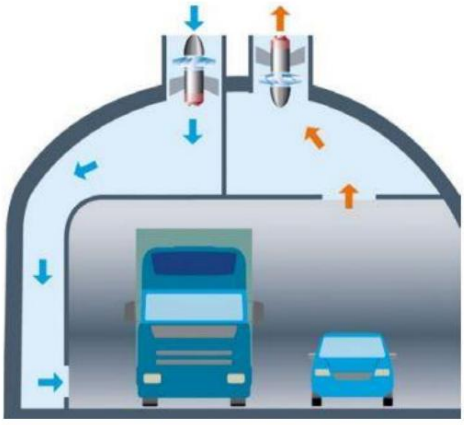
4. Smoke and gases mix with the air and are released from the end of the tunnel.
5. Airspeed is appropriate for traffic safety.

The longitudinal ventilation system is a ventilation solution for modern tunnels, characterized by simplicity, efficiency and automated control. Especially in areas with high traffic flow and rapid accumulation of hazardous gases, this system plays an important role in ensuring fire safety and human health. In the future, these systems are expected to be integrated with artificial intelligence-based control systems.



Longitudinal ventilation system





Mixed ventilation system

Mixed method (combination ventilation) is a combination of two or more ventilation systems used to provide ventilation in transport tunnels. In this system, longitudinal and transverse ventilation methods usually work together.

Mixed ventilation system— is a combination of longitudinal and transverse ventilation systems for air renewal and exhaust of polluted air in transport tunnels. Such systems in many cases provide high efficiency, depending on the length and characteristics of the tunnel.

The mixed ventilation system is characterized by its high efficiency and flexibility. By using this system, it is possible to renew the air in transport tunnels, effectively remove smoke and harmful

gases. Although the installation and maintenance costs of the system are high, its effectiveness and role in ensuring safety are important.

The mixed ventilation system is based on the following principles:

- First stage: The air moves in a longitudinal direction. This is useful, for example, when traffic is light or when there are high levels of smoke and gas.
- Second stage: Air is exhausted in a transverse direction, especially if there is a large amount of smoke or harmful gases in the air. In this case, a transverse ventilation system helps to quickly exhaust the air flow.
- Automatic control system: Sensors and detectors are used to monitor air quality and control ventilation in real time.

Mixed ventilation system is characterized by its high efficiency and flexibility. By using this system, it is possible to renew the air in transport tunnels, effectively remove smoke and harmful gases. Although the installation and maintenance costs of the system are high, its effectiveness and role in ensuring safety are important.

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