The analysis and discussion on ventilation and energy-saving of the tunnels of Long Highway

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Abstract. Along with the construction and development of highways in China, there are more and more tunnels in the highways, and their operational security and energy-saving have been paid wide attention to. The ventilation facilities for road tunnels are very important in the construction of electromechanical facilities in the tunnels of Changda Highway, and they are the important warranting facilities for the safe operation of the tunnels in Changda Highway [1]. The problems of large energy consumption and high operation expenditure of the tunnels in Changda Highway become more and more prominent day by day. Therefore, it is very important to research the secure and economic technology of tunnel energy-saving, especially the ventilation and energy-saving technologies for tunnels. This paper is based on the engineering of extra-long Wulaoshan Tunnel in Mojiang-Lincang Highway, and it researches the ventilation and comprehensive energy-saving of the tunnels in Changda Highway – it performs the detailed analysis and research in many aspects, such as the optimized design of ventilation facilities in the tunnels of Changda Road, the intelligent control of air blower, the energy-saving power supply and distribution facilities for ventilation as well as operation and managements, and it can provide technical references for the future development of energy-saving ventilation measures of the tunnels in Changda Highway.

1. Introduction
Since the 12th Five-year Plan, especially during the 13th Five-year Plan and 14th Five-year Plan, the construction mileage and traffic mileage highways in Yunnan Province have increased a lot; there is a breakthrough in quantity and quality, and shows a tendency of prosperous development; however, such tendency is restricted by the special geomorphic conditions of many mountains and small area of plateau in Yunnan-Guizhou Plateau. The proportion of the tunnels in the highways under construction of Yunnan Province is very large, while the energy consumption of tunnels in operation of the highways in mountainous area normally takes up for over 60% of energy consumption of highways in operation period. Various kinds of auxiliary facilities are set in the tunnels, such as ventilation, lighting, power supply and distribution, fire extinguishing and supervision. Among them, the ventilation facilities are the important facilities which can warrant secure operation of the roads in Wulaoshan Tunnel and increase the traffic efficiency, at the same time, they are also the electromechanical facilities with the largest energy consumption. The lowering-down of operational energy consumption of the tunnels is a complex engineering; the power consumption of the ventilation facilities in the tunnels of Changda Road is very large, and more power can be saved [2], therefore, this paper performs the relevant technical research in many aspects such as the optimized design of ventilation facilities, air blower control as well as the power supply and distribution facilities for energy-saving ventilation.
2. The research on the optimized design for ventilation of tunnels in Changda Highway

For the energy-saving in ventilation of the tunnels in Changda Highway, the design should be scientifically optimized in prior; the designer should determine rational design parameters and design value for tunnel ventilation, so as to improve the effects of tunnel ventilation and realize economical design. This paper takes Wulaoshan Tunnel in Mojiang-Lincang Highway as example: the analogue simulation is performed to the tunnels in Changda Highway with the analogue simulation software, the 3D numerical analysis is performed for vertical ventilation, and the distance between air blower and vault, the air outlet of the tunnel and many other design parameters have been optimized, so as to provide critical rationales for the ventilation plan and optimized design of configuration.

Wulaoshan Tunnel in Mojiang-Lincang Highway is located at AK262+640 – AK269+340 at the line with the full length of 6700m, and it is the extra-long tunnel. The overall tunnel is in the straight line and the both ends are located in curves; the vertical slope 1.9%. The two-section air-moving ventilation plan is used in both left and right lines of Wulaoshan Tunnel, and the jet fan is set at the exits and entrances of the tunnel as well as nearby air distributors and air outlets. The plain layout for ventilation is shown in Figure 1.

![Fig. 1. The plain layout for ventilation of Wulaoshan Tunnel](image)

(1) The 3D numerical analysis for vertical ventilation of the tunnel

Because Wulaoshan Tunnel is too long, it is very difficult to perform modelling analysis to the entire tunnel with the current commercial computation capability. The air flow in the two neighbouring units of jet fans is basically similar during the phase of sufficient development of air flow. According to the design information on tunnel ventilation, the interval among three groups of jet fans nearby the exits and entrances of the tunnel should be 300m. In order to analysis the optimized method of deploying jet fans at the entrance of the tunnel, the length of 300m is set as a numerical simulation section, and it is composed of the section at the rear of air blower entrance (50m) and the section at the front of air blower exit (250m). In order to analyze the pattern of air outlets in inclined shafts, the local modelling is done for the air distributors and air outlets at the inclined shafts. The vertical ventilation of the road tunnel is calculated according to monadic flow theory and the theoretical base for 1D regular computation of vertical ventilation of road tunnel is aerodynamics. This paper makes the simulation analysis to the dynamic and drag force pressure adjustment of jet fan in the tunnel under the effect of different wind speeds and the effect of changing wind speeds at the exit of jet fan to the performance of pressure adjustment with ANSYS FLUENT 15.0 – a software for fluid mechanics computation, the 3D model of air blowers in the tunnel is established and shown in Figure 2.
(2) The optimized setting of the distance between air blower and vault

By simulating computation, this paper researches the effect of the distance between air blower and vault to vertical ventilation. By changing the distance Z between the jet fan and vault, the designer can simulate the distribution of jet fan with the distance between air blower and tunnel of 15cm/20cm, as is shown in Figure 3-4.

Fig. 2. The sketch map on the 3D model of the air blowers in Wulaoshan Tunnel

Fig. 3. The vector diagram on the speed distribution of jet fan with the distance to the tunnel of 15cm

Fig. 4. The vector diagram on the speed distribution of jet fan with the distance to the tunnel of 20cm
The research indicates that, the larger the distance between air blower and tunnel is, the more collective the air speed at the air flower exit will be, and the flow regime will be more stable; therefore, it is recommended that the distance between the jet fan and the tunnel shouldn’t exceed 20cm when the jet fan is installed in Wulaoshan Tunnel. This is the rational design plan.

(3) The optimized design of the air outlet of tunnel

The combinative ventilation method of vertical shaft (inclined shaft) with jet fan is usually applied to the tunnels in Changda Highway. Therefore, the designer should pay attention to the size and form of air outlet section, the angle between air outlet and tunnel axle and other key parameters in ventilation design. Currently there are two forms of tunnel air outlets, one is shrunk diameter type and the other is expanded diameter type. When the air is flowing in tunnel and when the diameter of the tunnel shrinks locally, the potential energy of air flow will be converted to kinetic energy and the air flow speed will increase; this procedure will cause certain energy loss. When there is the local diameter expansion in the tunnel, the kinetic energy here will be converted to potential energy, the air flow speed will decrease and this procedure will also cause certain energy loss; when there is an air shunt, if the air flow speed and direction in front of and at the rear of the shunt node don’t change, the energy loss will be minimum.

This paper will perform the numerical simulation analysis. In order to simplify the calculation, the angle between the air outlet and the tunnel axle is set as 90 degrees, and a section of tunnel at air outlet with the length of 200m will be taken.

Figure 5 and Figure 6 are the vector diagrams of speed at the air outlet with shrunk diameter and expanded diameter respectively; comparing with the situation when no gradually expanded air duct is set, the symmetric gradually expanded air duct can improve the air exhausting efficiency of air exhaust duct obviously, and the ventilation effect will be more obvious.

3. The ventilation control of the tunnels in Changda Highway

The main control measures for tunnel ventilation facilities include direct control method, indirect control method, program control method, modern control method as well as fuzzy control method [3]. Many factors should be taken into consideration comprehensively for the ventilation control technology in Wulaoshan Tunnel, such as CO concentration, smog concentration and traffic flow, etc. Combining the
feedback value of key factors and the fuzzy PID control algorithm, the designer can perform intelligent control to the ventilation quantity in the tunnel. The control directive is shown in Figure 7 [4].

![Figure 7: The figure on control directives](image)

By rationally setting CO concentration, smog concentration and traffic volume sensor in the tunnel, the CO concentration and smog concentration in the tunnel are generally proportional to the distance from the tunnel entrance; the CO concentration and smog concentration at the tunnel exit are the highest, therefore, it is recommended to install the sensor CO concentration and smog concentration at the tunnel exit, and to install the traffic quantity investigating equipment at the tunnel entrance. The intelligent association between CO concentration/smog concentration and the launching and stopping of the air blower should be realized so as to increase the ventilation efficiency of the tunnel effectively and reduce the electric charge for the operation of air blowers in the tunnel.

4. The power supply facilities for the energy-saving ventilation in the tunnels of Changda Highway

The ventilation system in the tunnel is the load set for the success traffic in the tunnel, and it is normally set in the long tunnels and extra-long tunnels. The power supply facilities are mainly composed of two parts: air blower controlling cabinet and transformers. Therefore, to select the power supply facilities for air blowers with good power supply quality and obvious energy-saving effects are also an important measure for energy saving in the tunnel.

1. The selection of transformer

The electric transformer can be categorized into distribution transformer and box-type transformer, and the distribution transformer can also be categorized into oil-immersed transformer and dry-type transformer. The box-type transformers used in China are mainly European box-type transformer and American box-type transformer. As for the features of power consumption in the tunnels of highways in mountainous area, the main transformers used in the power supply and distribution systems in road tunnels include SCB-type resin insulation dry-type transformer, SG-type non-encapsulating type transformer, H-level dry-type transformer and amorphous alloy dry-type transformer. This paper recommends amorphous alloy transformer. Amorphous alloy is a kind of new energy-saving materials composing of many elements, and it can save 70-80% of no-load current (iron core) loss. The amorphous alloy material can not only extend the service life of the transformer, but also reduce the ferrous and excitation loss in the transformer, so as to warrant the highly-effective and stable operation.

2. Frequency conversion control technology

Currently the frequency conversion control technology has been applied in controlling axial air blower in the tunnels; the amount of launching current of the air blower is 6 times of the rated current of the motor, and the launching current will not exceed the rated current when the frequency conversion control technology is used, and the soft launching can be realized; besides, the energy-saving effect of the frequency conversion control technology is very obvious, and the rotation speed of the air blower in the tunnel can be controlled according to CO concentration and smog concentration in the tunnel, so that the energy consumption of air blower during operation can be largely saved.
5. The energy-saving ventilation and operation management of the tunnels in Changda Highway

The energy-saving ventilation and operation management of the tunnels in Changda Highway means to reduce the energy consumption for tunnel ventilation by reinforcing the tunnel operation and management system under the prerequisites of warrant secure tunnel operation.

(1) Reinforcing the ventilation and operation management of the tunnel, establishing precise ventilation management system, defining the launching time, operation condition and operation level of ventilation facilities in the tunnels and preparing effective ventilation management measures so as to increase the ventilation and operation efficiency in the tunnels.

(2) Maintaining the ventilation equipment in the tunnels strictly according to the regulations on electromechanical facility maintenance so as to make the ventilation facilities in the tunnel have the maximum efficiency.

(3) Consummating the standard and regulation system for the ventilation and energy-saving in the tunnels, and determining the goal of ventilation energy-saving in the tunnels after taking the traffic quantity in the tunnel, used years of tunnels and the updating of new technology into consideration comprehensively.

6. Conclusion

During constructing Changda Tunnel, the ventilation planning and the effect of ventilation operation have a direct relevance to the cost of tunnel engineering, operational environment, fire-extinguishing functions and operational benefits. The purpose of this paper researching the energy-saving ventilation technology and low energy consumption in the tunnels of Changda Highway (Wulaoshan Section) is to select the proper parameters for ventilation design and find out the ventilation mode, energy-saving control for ventilation system as well as power supply and distribution facilities for ventilation and other technologies which are suitable for the tunnels in Changda Highway, and it will provide the road users with more cozy and humanized ventilation and energy-saving measures.

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