New Control Method Based on Wujiu Green Highway Tunnel Lighting

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Abstract. Highway tunnel lighting is an important guaranteed condition for safe operation. In engineering applications in recent years, LED lamps, as the recommended road tunnel lamps, have the characteristics of good color rendering, fast start-up, and good energy-saving effect, but the color temperature of different LED lamps is also very different, and different color temperatures are used in tunnels. The LED lamps will have different effects on the driver. However, the current design specification only specifies the illuminance, brightness and uniformity of the lighting indicators, and does not list the color temperature values of lamps that can be used in tunnels of different lengths and speeds, resulting in the choice of tunnel lighting color temperature. It will bring adverse effects and hidden dangers to the safety of tunnel operation. Therefore, adjusting the color temperature value of tunnel lighting is of great significance to the driving safety and comfort of drivers in the tunnel. Combined with the tunnel lighting design of the Wudu to Jiuzhaigou section of the G8513 Pingmian Expressway, the control method of stepless dimming is recommended in this paper through the technical comparison of tunnel lighting control to create a green highway design concept. It can be concluded that when lamps with medium and high color temperature values are used in tunnels, drivers can improve the recognition and response speed of the surrounding environment, which is beneficial to driving safety. Tunnel lighting color temperature adjustable control technology is the way to achieve this goal, and ultimately meet the driving safety requirements, improve the driver’s driving comfort, and achieve accurate and efficient dimming of each section of lighting in the tunnel.

Keywords. Highway tunnel, green highway, variable color temperature, human vision, intelligent control

1. Overview

In recent years, Gansu Transportation has closely responded to the requirements of the country, the industry and the province to implement the concept of ecological civilization and green development. The level of green construction has accumulated rich experience in green highway construction. In the process of building green highways, tunnel lighting project is one of the contents that can fully reflect green
highways. The control method of tunnel lighting lamps is the key point and core point to realize the realization of highway green lighting. The highway tunnel lighting control technology can ensure the safe operation of the road and achieve the goal of energy saving. Through the control and adjustment of the lamps, the comfort and safety of the driver in the tunnel can be improved, which is an important part of the implementation of the green highway concept.

2. Engineering Background

The route from Wudu to Jiuzhaigou of G8513 Pingmian Expressway is 99.788Km long. There are 32 tunnels along the route. The total length of a single tunnel is 87960m, and the length of bridges and tunnels accounts for 80.96% of the total length of the route. It has been listed as the second batch of typical demonstration projects for green highway construction by the Ministry of Transport. Highway tunnel lighting system is not only an important safety guarantee facility, but also the largest operational energy consumption load of highway operation. The operating cost of lighting facilities in tunnels is high, so the issue of tunnel lighting energy saving will be an important part of building a “green highway”. In recent years, with the development of LED technology becoming more and more mature, the application scale of this new energy-saving light source in the field of highway has shown a rapid upward trend, but the advanced nature of its performance indicators has not been effectively utilized, which is highlighted in the fact that the lighting control method is too simple, It is far from realizing the full excavation of the safety, comfort and energy-saving potential of LED light source lighting. At this stage, it is urgent to give full play to the light and color-adjustable LED light source, which can fully meet the advantages of the driver’s human visual perception. With the dual goals of safety and energy saving, we should seize the key issues of road tunnel lighting safety and comfort requirements, and improve the safety and operation efficiency of expressways in the tunnel environment can reduce expressway operating costs on the basis of ensuring safety, and improve expressway management and service levels in Gansu Province.

3. Commonly Used Tunnel Lighting Control Methods

At present, there are two control methods for road tunnel lighting, graded dimming and stepless dimming. Hierarchical dimming is to control the lamps through the opening and closing of multiple lighting circuits through contactors. This control method is simple and easy to implement, but multiple lighting sub-circuits need to be set up from the terminal distribution box, and corresponding wiring will also be added. The amount of cable works is not conducive to saving investment. Moreover, after turning off the lamps of a lighting circuit, a “zebra effect” may occur, which is not conducive to the driving safety of drivers. The stepless dimming control method adopts LED lamps with dimmable color temperature. Through the cooperation of the host chip and the task of the independent controller, the color temperature and brightness in the tunnel can be adjusted. This control method does not need to set up many lighting sub-circuits, which can save energy. Cables, reduce investment, do not need to use contactors to control the opening and closing of lighting circuits, can extend the service life of lamps and lamp maintenance cycles, effectively reduce engineering costs, and will not cause “zebra
The stepless dimming control method can also bring visual comfort to the driver. Driving in many long tunnels, due to the closedness and monotony of the tunnel environment, drivers are prone to visual fatigue, depression and tension, which is not conducive to safe driving. The function of tunnel lighting not only needs to ensure that the driver can see the obstacles within the line of sight, but also needs to meet the brain stress response of the driver when the driver suddenly enters the tunnel in a bright environment. Therefore, the control and adjustment of lighting plays a very important role. It needs to be adjusted to the brightness and color temperature that the human eye can quickly adapt to. When the weather is sunny during the day, the tunnel entrance section should be adjusted to a color temperature close to natural light; if it is rainy, lowering the color temperature is more suitable for the environment outside the tunnel, and drivers will not feel uncomfortable when driving into the tunnel; Reducing the color temperature in the hole to a low value is beneficial to energy saving and improving human eye comfort. Therefore, this control method has been used more and more in the design of highway tunnel lighting control.

4. The Influence of Light Source Color Temperature on Drivers

In the design of highway tunnel lighting, the main factor that affects the driver’s visual effect and accurately identifies surrounding obstacles is the brightness index. Most of the applied research is to divide the tunnel lighting design into the entrance section, the transition section and the middle section with different brightness and set different power LED lamps, but little attention is paid to the impact of color temperature on the driver’s vision and lighting effects. In recent years, due to the continuous implementation of long tunnels, many domestic and foreign experts have begun to study the visual effects of lighting in the environment of long tunnels, and have deeply discovered the impact of color temperature on human vision. The color temperature of the light source can have an important impact on the color of the surrounding environment and objects. Tunnel lighting with different color temperatures will bring different visual impacts and changes in psychological states [2]. Studies have shown that, for example, blue cold light makes people feel faster, nervous and cold, while yellow and red warm light can relieve emotions and bring people a warm feeling. People’s visual perception produces corresponding reflections with the change of different color temperatures, and also makes different reflections on the recognition of surrounding objects. The research results show that in the high color temperature lighting environment, obstacles rich in short-wave components are easier to identify. Therefore, in order to achieve better lighting effects, a high color rendering light source should be selected in the tunnel lighting design. This is also critical to the impact of drivers entering the tunnel. The cold and warm color temperature will affect the human eye’s recognition of surrounding objects, and the current mainstream design of tunnel lighting control still only considers the brightness factor, while ignoring the effect of color temperature. There is a deviation in the judgment of obstacles when driving in the tunnel. Therefore, based on the influence of this important factor, it is necessary to integrate the change of color temperature into the tunnel lighting design, which can make the driver more comfortable and accurate when driving in the tunnel. Visual experience. The above research results only consider the impact of light source color temperature on vision, but do not consider how the color temperature affects the
driver’s fatigue driving. As we all know, long-term fatigue driving in tunnels is a very dangerous safety hazard, which will lead to serious traffic accidents. Many preventive measures have been taken against the hazards of fatigue driving, including the color temperature of the light source. When driving in a long tunnel, unlike driving outdoors in natural light, it is easier to cause visual fatigue in the tunnel, and the ordinary artificial lighting in the tunnel can no longer meet the requirements of the human eye for object recognition. For the scientific lighting control method is particularly important. Xiao Yuhan, a domestic expert, used laboratory simulation to simulate the environment in the road tunnel, and tested LED lamps with different brightness and different color temperatures. Reducing the pupil diameter can reduce the visual fatigue of drivers and improve visual sensitivity. The higher the color temperature, the more obvious the inhibitory effect on fatigued driving. To sum up, the indicator of color temperature can affect the driver’s judgment on the preparation of surrounding obstacles, restrain fatigue driving, and ensure driving safety.

5. Tunnel Lighting and Visual Relationship

5.1. Three States of Human Vision

The long tunnel is generally divided into four sections, the entrance section, the transition section, the middle section and the exit section. When the driver passes through the entrance section of the tunnel, the visual recognition of the human eye is photopic vision. Visual identity is intermediate vision. Visual sensitivity varies with different light wavelengths, and the following is an analysis table of spectral light efficiency under three visual conditions in Table 1.

The lighting source with high color temperature and blue light can effectively reduce visual fatigue and improve the sensitivity of human eyes in Figure 1.

5.2. Visual Process

When driving in a long tunnel, the driver needs to constantly identify and judge the surrounding road conditions, the vehicles in front and back, and the surrounding environment, and then make corresponding driving operations. Therefore, the whole driving process is to perceive, and the three processes of judgment and operation are constantly reciprocating [3]. Perception is that people recognize information such as the surrounding environment, road conditions, traffic signal instructions, and people walking through the human body’s sensory organs (sight, hearing, touch); judgment means that the driver collects the previous stage information based on the combination of driving experience, so that the brain analyzes and judges the above information, and issues physical instructions; operation means that the driver completes the driving operation control of the vehicle through the brain instructions. These three processes are shown in Figure 2.

The first stage, the information perception stage, is the most important stage in the driving process. If there is a difference in the perception of information, it will seriously affect the subsequent manipulation and control of the vehicle. Therefore, it is very necessary to improve the accuracy of the perception information. Especially after entering the tunnel and driving to the middle of the tunnel, since there is no natural light, only the human eye can perceive the surrounding information, so the excellent
lighting effect can provide the necessary conditions for the driver to perceive the surrounding environment and ensure the driver’s basis. Identify the information to make correct driving judgments.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Classification</th>
<th>The most sensitive wavelength of the human eye</th>
<th>Luminous Efficacy Maximum</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Driver vision</td>
<td>490 nm</td>
<td>3850lm/W⁻¹</td>
<td>High color temperature light source with more blue light can reduce visual fatigue and improve visual acuity</td>
</tr>
<tr>
<td>2</td>
<td>photopic vision</td>
<td>555 nm</td>
<td>683lm/W⁻¹</td>
<td>The brightness changes from bright to dark, and the wavelength of light that the human eye is sensitive to becomes lower</td>
</tr>
<tr>
<td>3</td>
<td>dark vision</td>
<td>507 nm</td>
<td>1700lm/W⁻¹</td>
<td>Outgoing line visual deviation law phenomenon</td>
</tr>
</tbody>
</table>

Figure 1. Spectral light efficiency curves of three kinds of vision.

6. Color Temperature Definitions and Solutions for Adjusting Color Temperature

6.1. Definition of Color Temperature

The color temperature of a light source is determined by comparing its color to a theoretical thermal blackbody radiator. A thermal black body radiator is a black body, which is an ideal physical model, and the absorption rate of radiant energy of any wavelength at any temperature is equal to 1 [4]. The color of the black body emits light in a one-to-one correspondence with the temperature. When we describe the color of a certain light source, it is often compared with the color of the black body. If the color of the light emitted by the light source is the same as the color emitted by the black body at a certain temperature, then this color of the light source is called the
temperature color, or the temperature color for short. It is now commonly referred to as color temperature.

![Diagram](image)

**Figure 2.** Three stages of the driver’s driving process.

### 6.2. Color Temperature and Visual Fatigue in a Low-Brightness Environment in a Tunnel

Drivers who drive in low-brightness environments in tunnels for a long time will be affected by both lighting brightness and lighting color temperature. The lighting environment with high color temperature will make people feel excited, and the lighting environment with low color temperature will make people feel fatigued, which will further affect the driver’s information collection and corresponding operation. When people suffer from visual fatigue, there will be blurred vision, wrong judgment, slow response, etc., they cannot give timely and correct feedback to sudden situations, and the response speed will also decrease. Therefore, the light environment in the tunnel will have an important impact on human vision. If the color temperature can be adjusted timely and accurately according to the change of light outside the tunnel to a state that the human eye can quickly adapt to after entering the tunnel, it can provide drivers with good driving conditions. Comfort and safety, thereby reducing accident rates [5]. The effect of color temperature on human vision is as follows in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Color temperature value</th>
<th>Reaction time</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High color temperature</td>
<td>7500K, 8500K, 9500K</td>
<td>880ms</td>
<td>Less reaction time</td>
</tr>
<tr>
<td>2</td>
<td>Medium color temperature</td>
<td>4500K, 5500K, 6500K</td>
<td>962ms</td>
<td>Less reaction time</td>
</tr>
<tr>
<td>3</td>
<td>Low color temperature</td>
<td>2500K, 3500K</td>
<td>1106ms</td>
<td>Longer reaction time</td>
</tr>
</tbody>
</table>

Table 2. Effect of color temperature on human vision.
It can be seen that in the medium and high color temperature environment, the human eye has less time to respond to the information after the information is collected, and the low color temperature environment will increase the human eye’s information response time, which is not conducive to driving safety. However, it is not the case that the higher the color temperature value, the better. An excessively high color temperature value will also prolong the reaction time of the human eye. Therefore, appropriately increasing the color temperature value of the lamps in the middle section of the tunnel in the design can enable the driver to more accurately identify the surrounding environment and shorten the time of the human eye. Eye reaction time effectively reduces the accident rate and ensures driving safety.

6.3. Color Temperature Adjustment Scheme

At present, the following five technical solutions are often used to realize the adjustment of color temperature in Table 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Color temperature adjustment scheme</th>
<th>Advantages and disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Create white light by combining red, green and blue LED lights</td>
<td>Low difficulty and high stability</td>
</tr>
<tr>
<td>2</td>
<td>Controlling the combination between chips of LED lighting fixtures and regulating current</td>
<td>Technical solutions are difficult</td>
</tr>
<tr>
<td>3</td>
<td>Control the brightness of the three colors of white, blue and red</td>
<td>Low stability</td>
</tr>
<tr>
<td>4</td>
<td>Combination of white and yellow light</td>
<td>Difficult to adjust</td>
</tr>
<tr>
<td>5</td>
<td>Mix low color temperature white light with high color temperature white light and adjust its brightness</td>
<td>Low difficulty, stepless adjustment</td>
</tr>
</tbody>
</table>

The above 5 solutions can adjust the color temperature, but in terms of operability, adaptability, and the effect achieved, the fifth technical solution is the easiest to implement, with less difficulty and the best effect. The color temperature adjustment technology used.

6.4. Principle of Dimming and Color Temperature

Based on the above description of the color temperature adjustment scheme, this Wujiu Road tunnel lighting control adopts the fifth scheme to realize the color temperature adjustment. The specific color temperature adjustment methods are as follows in Table 4.

Through the summary and comparison of the above table, the pulse width modulation method is the best choice, which is not only suitable for the humid and cold environment of the tunnel, but also easier to implement and has higher stability.

<table>
<thead>
<tr>
<th>No.</th>
<th>Dimming method</th>
<th>Dimming principle</th>
<th>Advantages and disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Analog dimming</td>
<td>Adjust the resistance value to change the current</td>
<td>Limited adjustment range</td>
</tr>
<tr>
<td>2</td>
<td>SCR dimming</td>
<td>Adjust its opening angle</td>
<td>High environmental requirements, not suitable for tunnel environment</td>
</tr>
<tr>
<td>3</td>
<td>pulse width modulation</td>
<td>Change the duty cycle of the digital pulse signal</td>
<td>High stability, enabling wide-ranging dimming</td>
</tr>
</tbody>
</table>
6.5. PWM Technology Dimming and Color Temperature System

The tunnel lighting controller issues a digital command, and the digital-to-analog conversion module in the system converts the digital signal into an analog voltage signal, which is input to the chip interface of the LED lamp. The driving principle of the chip to the LED lamp is different from the conventional switch driving principle. It has the advantages of resisting overvoltage, overcurrent and inrush current. At present, there are two types of single-chip white light LEDs and multi-chip white light LEDs. Therefore, changing the material of the chip can easily change the color temperature of the lamp, and the adjustable color temperature range of the lamp can be very large. This method can extend the service life of the lamp to a greater extent and improve reliability. It solves the disadvantage that the color temperature of LED lamps is not adjustable, and plays a key role in the application of color temperature adjustment of LED tunnel lights. The chip itself has a dimming port, which can monitor the status of tunnel LED lamps, control lamp switches, and adjust color temperature in Figure 3.

The tunnel lighting controller sends commands through the bus to monitor the working status and fault points of each lamp in real time, and perform accurate digital dimming according to actual requirements. This digital dimming can be used in long distances and large interference environments. It can also work normally, and has strong compatibility, which can realize the perfect combination of energy saving and high-efficiency lighting.

7. Specific Applications of Color Temperature Adjustment Control System

This system is applied to the enhanced lighting section at the entrance and exit of the Wujiu Green Highway Tunnel. When the environment outside the tunnel is strong light, the lighting power inside the tunnel increases and the brightness increases; when the environment outside the tunnel is cloudy and weak light, the lighting power inside the tunnel increases becomes smaller, that is, the illumination brightness is reduced. Based on the basic principle of dimming and color temperature of tunnel lighting, an intelligent control system for tunnel lighting is designed. By collecting the light environment data outside the tunnel, and according to the calculation result of color temperature and brightness inside the tunnel, the reinforced section is dimmed and toned. Adjust the brightness and color temperature of the lighting at the entrance and exit and in the cave to achieve the purpose of energy saving and ensure driving safety.

The tunnel lighting intelligent control system is composed of the host, the main controller, the data collector, the sub-controller, the lamps, and the monitoring software [6]. The data collector inputs the collected brightness data outside the tunnel into the main controller for data processing, and then transmits it to the sub-controller by the communication system. The sub-controller has the functions of remote control and local control. Brightness and color temperature can be adjusted. The tunnel LED lamp is also different from ordinary tunnel lighting lamps. It is composed of low color temperature light beads and high color temperature light beads with two different color temperature light beads, such as 3250K and 6250K color temperature. By setting different power ratios for the two-color temperature lamp beads, the color temperature and brightness can be adjusted. For example, different color temperature and power can be set at different time periods. In the morning, when the light outside the cave is weak, set it to 3500K, 4500K, and 5500K respectively; the light outside the cave at noon
When it is strong, it is set to 6000K, and after 16:00 in the afternoon, it is set to 5500K, 5000K, and 4500K respectively. The specific setting value still needs to be determined according to the actual terrain and weather conditions on the site. In principle, it is divided into the following four control situations in table 5.

![Figure 3. Principle classification of color temperature control schematic diagram of architecture of digital dimming, color matching and temperature lighting system.](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Before the change of color temperature outside the cave</th>
<th>After the color temperature changes outside the cave</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;6000K</td>
<td>&lt;6000K</td>
<td>Entry section</td>
</tr>
<tr>
<td>2</td>
<td>&lt;6000K</td>
<td>&gt;6000K</td>
<td>Entry section</td>
</tr>
<tr>
<td>3</td>
<td>&lt;6000K</td>
<td>&lt;6000K</td>
<td>Entry section</td>
</tr>
<tr>
<td>4</td>
<td>&gt;6000K</td>
<td>&gt;6000K</td>
<td>Entry section</td>
</tr>
</tbody>
</table>

The fine adjustment of brightness can realize the adjustment of the tunnel LED lighting with the change of the brightness of the natural light outside the tunnel, so as to achieve the purpose of lighting on demand and save the energy consumption of the tunnel lighting; The change of the color temperature of the natural light environment can be adjusted to reduce the visual impact caused by the inconsistent color temperature of the light environment inside and outside the tunnel, and improve the comfort and safety of tunnel LED lighting in Figure 4.

After the implementation of this technology, the color temperature and brightness of the lighting environment in the tunnel can be dynamically adjusted according to the change of the color temperature and brightness of the light environment outside the tunnel, so as to improve the visual comfort and safety of drivers (Figure 5). The light and color dual-index controllable tunnel LED lighting adopts two sets of high and low
color temperature LED tubes for redundant design. Compared with the single-color temperature tunnel LED lighting, the color temperature can be adjusted. It can be used by reducing consumption to meet the same lighting brightness requirements. Significantly reduce the heat generation and light decay speed of tunnel LED lighting fixtures, and significantly extend the service life of LED tubes. The refined brightness adjustment function can solve the problem of excessive lighting and save the energy consumption of tunnel lighting. Has significant economic benefits. The fine adjustment of color temperature improves the driving comfort and safety of the tunnel LED lighting environment, reduces the risk of traffic accidents in the tunnel, and improves the safety level of tunnel lighting in Gansu Expressway, which has significant social benefits.

Figure 4. Variation of lamp emission spectrum within temperature regulation range.

(a) 2700k light color temperature (b) 3500K light color temperature (c) 4500k light color temperature

(d) 5500k light color temperature (E) 6000K light color temperature

Figure 5. Visual effect of tunnel lighting environment after color temperature adjustment.
8. Conclusion

The requirements of modern highways for lighting are gradually changing to green and scientific. The use of this intelligent control technology with variable color temperature in road tunnels can effectively and accurately adjust the color temperature of lamps according to the changes of light outside the tunnel. This method can further achieve the purpose of green energy saving, reduce operating electricity costs, and more importantly, improve the comfort and safety of driving in the tunnel, it is of great significance to improve driving safety and reduce the occurrence of accidents. The color temperature control technology is mainly considered to be applied to the tunnel of Wujiu Road with a design speed of 80km/h. However, due to the fact that there are few manufacturers producing LED tunnel lamps with variable color temperature, and there is no corresponding technical specification to support it, it is used in other projects. In the specific design, it is necessary to calculate and study according to factors such as tunnel length, driving speed, and brightness, and finally determine the specific color temperature value of LED lamps.

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References