

The effect of segmented lighting on tunnel lighting energy-saving

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Abstract. The aim of this study is improving the effect of tunnel lighting intelligent control system on tunnel lighting energy-saving. Firstly, there are threshold zone, transition zone, interior zone and exit zone in a tunnel basing on the *JTG-2014* in China. Then the structure and workings of tunnel lighting intelligent control system are given. The control system uses the method of “vehicle in, light brightens; vehicle out, light darkens” to save energy, and it is worthy for energy-saving. Further, in order to achieve energy-saving more on the basis of the system equipment, segmented lighting is proposed. The working-steps of segmented lighting are listed. The adjustment of LED lamps’ luminance is not synchronous in a tunnel. The LED lamps of threshold zone and transition zone are adjusted to their minimum luminance earlier than interior zone and exit zone for more energy-saving. Finally, the effects of tunnel lighting intelligent control system with and without segmented lighting are compared in energy-saving. Segmented lighting has obvious effect on energy-saving, especially for longer tunnel.

1.Introduction

With the development of highway tunnels, the energy-saving of tunnel lighting has been paid more and more attention. According to the tunnels in HeDa highway, electric power consumption of tunnel lighting system accounting for more than 70% of tunnel total energy consumption in operating a tunnel. In order to avoid the waste of energy, tunnel lighting intelligent control systems are went into service.

In recent years, there are many studies in tunnel lighting energy-saving. In 2004, Clipsal of Australia studied tunnel lighting intelligent control technology, and developed a highway tunnel intelligent lighting control and management system [1]. In 2010, Chao Yang and others used fuzzy control method in tunnel lighting system [2]. In 2012, Sonjia H M Leung reviewed the LED lighting technology and stresses on its application to address the long tunnel lighting design requirements and special railway tunnel environment, proposing the adjustment of tunnel lighting to reality [3]. In 2015, Li Shuguang presented a tunnel lighting optimal control model in considering traffic safety and energy-saving problems, meeting the demand brightness and total average brightness constraints, and having a notable energy-saving effect [4]. In 2017, Shen researched the sub-section of tunnel lighting, analyzed the advantages and disadvantages of various dimming control schemes in tunnel control lighting system in detail and proposed an intelligent dimming control scheme for tunnel lighting [5].

Although many studies have applied to tunnel lighting intelligent control system, there are still some improving spaces for energy-saving effect. Based on the operation experiences of 18 tunnels in HeDa highway in Jilin Province, China, this paper applies segmented lighting into tunnel lighting intelligent control system for perfecting the effect of energy-saving.



2. Tunnel lighting standard and system

2.1 Tunnel lighting standard

All the operations in tunnel must observe *Guidelines for Design of Lighting of Highway Tunnels (China, JTG-2014)* standard in China. According to the standard, the longitudinal section of the tunnel is divided into four zones with different levels of demand luminance: threshold zone, transition zone, interior zone and exit zone (each zone could be divided into 2 or 3 smaller zones) [6, 7]. The adaption curve of the luminance in tunnel is shown in Figure 1. $L_{20}(s)$ is adaptation luminance. L_{th1} , L_{th2} , L_{tr1} , L_{tr2} , L_{tr3} , L_{in} , L_{ex1} and L_{ex2} are luminance of threshold zone 1, threshold zone 2, transition zone 1, transition zone 2, transition zone 3, interior zone, exit zone 1, and exit zone 2.

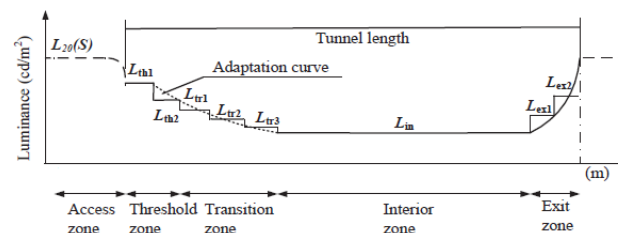


Fig. 1. The adaption curve of the luminance in tunnel.

According to Figure 1, the luminance of threshold zone and exit zone are higher than transition zone and interior zone. Because of the black hole effect and white hole effect [8], tunnel lighting uses those luminance to create a favourable visual environment and ensure traffic safety for drivers.

2.2 Tunnel lighting intelligent control system

For most tunnel lighting intelligent control systems, the system consists of those 5 more important parts: environment information sensing sub system, vehicle behavior perception subsystem, illumination real-time monitoring subsystem, tunnel lighting and light modulation subsystem and tunnel lighting communication subsystem [9]. And the system uses the control method of “vehicle in, light brightens; vehicle out, light darkens” to realize energy-saving [10].

2.2.1 System structure

Based on the operation of the 18 tunnels in HeDa highway, the structure of tunnel lighting intelligent control system is shown in Figure 2. And this system has been running more than 1.5 years in HeDa highway.

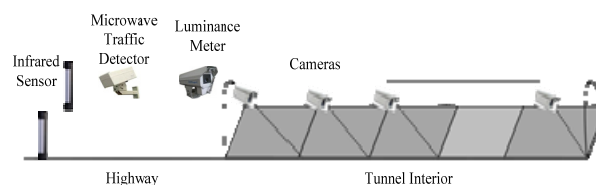


Fig. 2. The structure of tunnel lighting intelligent control system.

According to Figure 2, system uses the infrared sensors and the microwave traffic detectors to sense whether the vehicles are about to enter the tunnel. System uses the luminance meter to measure real-time adaptation luminance. System uses the cameras located in tunnel to judge whether there are vehicles in tunnel.

2.2.2 The workings of system

Tunnel lighting intelligent control system works the control method of “vehicle in, light brightens; vehicle out, light darkens” for energy-saving. The workings of system are shown in Figure 3.

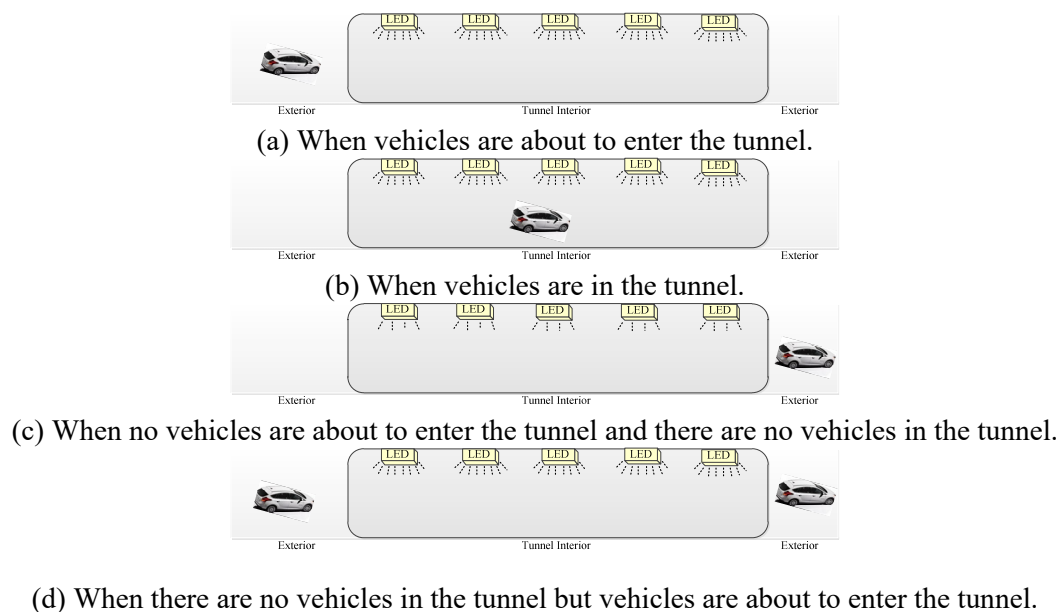


Fig. 3. The workings of system.

According to Figure 3, the system works as follow. When the infrared sensors and the microwave traffic detectors sense vehicles are about to enter the tunnel, the LED lamps in tunnel are adjusted to the demand luminance. And the demand luminance is calculated by the real-time adaptation luminance and the speed of vehicles which are sensed from the luminance meter and microwave traffic detector located tunnel exterior. When the cameras located in tunnel judge there are no vehicles in the tunnel and no vehicles are about to enter the tunnel, the LED lamps in tunnel are adjusted to their minimum luminance.

2.2.3 Energy-saving effect

Tunnel lighting intelligent control system has obvious effect in energy-saving. Based on the operation of the 18 tunnels in HeDa highway, tunnel lighting intelligent control system saves about 40% energy on average.

In order to meet the needs of energy-saving, tunnel lighting intelligent control system need some extra equipment, including infrared sensors, the microwave traffic detectors, optical transceiver, LED dimming controller and server. The cost of extra equipment is about 155,000 CNY. But tunnel lighting intelligent control system can save 113,150 CNY per year (The detailed data can be seen in Table 2, and electricity pricing is 1.0 CNY per kilowatt-hour in China). And the lifetime of LED is about 5 years. So, tunnel lighting intelligent control system is worthy for saving energy.

3.The segmented lighting

For a tunnel lighting system, the number of LED lamps is different based on the difference of the demand luminance and length in each zone of tunnel. The power consumption of the 4 zones in Chaoyang Tunnel (in Tonghua City, Jilin Province, China) of HeDa highway is shown in Table 1.

Table 1. Each zone's power consumption of Chaoyang Tunnel

	Length (m)	The number of LED lamps	Power consumption per day(kWh)	Power consumption per unit length (kWh/m)
Threshold zone	90	120	440.4	4.89

Transition zone	150	86	92.6	0.62
Interior zone	2805	311	224.0	0.08
Exit zone	60	36	45.6	0.76

According to Table 1, the power consumption per unit length of threshold zone and transition zone are higher, especially threshold zone. Threshold zone and transition zone cost more than 60% of the tunnel power consumption. It could save more energy by adjusting LED lamps of threshold zone and transition zone to their minimum luminance when the vehicles drive into interior zone. This method called segmented lighting in this paper.

3.1 The working-steps of segmented lighting

Segmented lighting is implemented in “vehicle in, light brightens; vehicle out, light darkens” tunnel lighting intelligent control system. According to the four zones in a tunnel, LED lamps in threshold zone and transition zone are adjusted to their minimum luminance when the vehicles drive off transition zone. The working-steps of segmented lighting are shown in Figure 4.

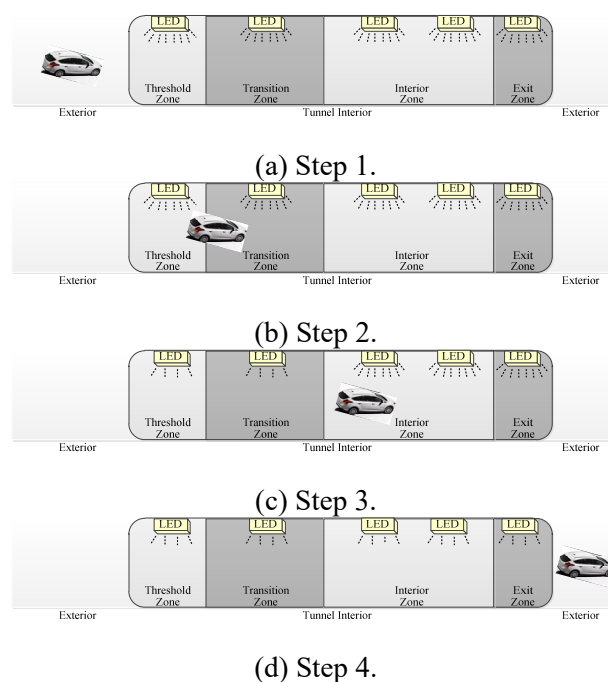


Fig. 4. The working-steps of segmented lighting.

According to Figure 4, segmented lighting works as follow. Step 1: when vehicles are about to enter the tunnel, same as the normal control system, all the 4 zones in the tunnel are adjusted to the demand luminance. Step 2: when there are vehicles in threshold zone and transition zone, all the 4 zones in the tunnel are kept the demand luminance. Step 3: when the vehicles drive off transition zone, no vehicles are about to enter the tunnel and there are no vehicles in threshold zone or transition zone, threshold zone and transition zone are adjusted to the minimum luminance. Step 4: when there are no vehicles in the tunnel but vehicles are about to enter the tunnel, all the 4 zones in the tunnel are adjusted to the minimum luminance.

3.2 The effect of segmented lighting

Basing on the 18 tunnels in HeDa Highway from Jan, 2017 to now, tunnel lighting intelligent control system with segmented lighting has obvious effect in energy-saving. In Jun, 2017, for each tunnel of HeDa Highway, 3 days with the similar weather and traffic volumes (the maximum is 1079 vehicles per day and the minimum is 1036 vehicles per day) are chosen to compare the power consumption. The power consumption of tunnel lighting without control system, tunnel lighting intelligent control system and control system with segmented lighting is shown in Table 2. The power consumption of each mode is got from ammeter in tunnel. The power saving is compared with tunnel lighting without control system, and the power saving of control system with segmented lighting minus the power saving of tunnel lighting without control system is the more power saving.

Table 2. The comparison of power consumption with 3 modes

Length of tunnel (m)	Tunnel lighting without control system	Tunnel lighting intelligent control system		Control system with segmented lighting	
	Power consumption (kWh/day)	Power consumption (kWh/day)	Power saving	Power consumption (kWh/day)	The more power saving
660	612	295	51.8%	279	2.6%
810	619	300	51.5%	280	3.2%
1018	632	319	49.5%	293	4.1%
1150	646	333	48.5%	300	5.1%
1270	660	344	47.9%	304	6.1%
1404	664	348	47.6%	306	6.3%
1520	675	346	48.7%	299	7.0%
1770	695	387	44.3%	331	8.1%
1777	696	389	44.1%	332	8.2%
2024	716	406	43.3%	339	9.4%
2250	734	429	41.6%	354	10.2%
2370	744	440	40.9%	360	10.8%

2520	756	453	40.1%	367	11.4%
2970	792	490	38.1%	387	13.0%
3080	803	488	39.2%	380	13.4%
3215	810	511	36.9%	399	13.8%

According to Table 2, segmented lighting has obvious effect on energy-saving, especially for longer tunnel.

4. Conclusions

In this paper, tunnel lighting intelligent control system designed by *Guidelines for Design of Lighting of Highway Tunnels (China, JTG-2014)* standard is expound. Basing on experience from 18 tunnels in HeDa highway, the effect of control system on energy-saving is obtained. Tunnel lighting intelligent control system is worthy for saving energy.

In order to achieve energy-saving more on the basis of the system equipment, segmented lighting is proposed. The working-steps of segmented lighting are listed. Because threshold zone and transition zone cost more power consumption, LED lamps in threshold zone and transition zone are adjusted to their minimum luminance when the vehicles drive off those zones for more effective energy-saving. The effects of tunnel lighting intelligent control system with and without segmented lighting are compared in energy-saving. Basing on the operation on 18 tunnels in HeDa Highway more than 1.5 years, segmented lighting has obvious effect on energy-saving, especially for longer tunnel.

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