Energy-Saving Tunnel Illumination System Based on LED’s Intelligent Control

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Abstract. At present there is a lot of electric energy wastage in tunnel illumination, whose design is based on the maximum brightness outside and the maximum vehicle speed all year round. LED’s energy consumption is low, and the control of its brightness is simple and effective. It can be quickly adjusted between 0-100% of its maximum brightness, and will not affect the service life. Therefore, using LED as tunnel’s illumination source, we can achieve a good energy saving effect. According to real-time data acquisition of vehicle speed, traffic flow and brightness outside the tunnel, the auto real-time control of tunnel illumination can be achieved. And the system regulated the LED luminance by means of combination of LED power module and intelligent control module. The tunnel information was detected by inspection equipments, which included luminometer, vehicle detector, and received by RTU(Remote Terminal Unit), then synchronously transmitted to PC. After data processing, RTU emitted the dimming signal to the LED driver to adjust the brightness of LED. Despite the relatively high cost of high-power LED lights, the enormous energy-saving effect and the well-behaved controllability is beyond compare to other lighting devices.

1. The present condition of tunnel lighting

The tunnel includes entrance section, transition section, middle section and exit section¹, lighting requirement of different tunnel section is different, even though the same section in different condition has different lighting requirement, which concerns outside brightness, traffic flow, vehicle speed, and so on².

Now most of tunnels adopt high pressure sodium lamp(HPS) to light, since HPS starts up slow and can’t dim light³, still using it can’t guarantee the tunnel brightness uniformity and smooth transition between the different sections. Despite LED tunnel lamp has been applied in tunnel, the controlling methods have no difference with high pressure sodium lamp’s, which almost adopt simple stepping control or loop control. These methods have not considered the factors that concern tunnel lighting such as outside brightness, outside weather, vehicle speed, traffic flow, and this often leads to the brightness exceeds actual demand, and results in energy wastage⁴. Therefore the important problem that needs to be solved in tunnel lighting control is real-time tracking the traffic flow and the outside

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brightness, adopting different intensity light to illuminate, and then improving the tunnel lighting and its distribution.

1.1. The features of LED lamp as lighting source
LED’s luminous efficiency is better compared with traditional HPS and fluorescent lamp, in the case of the same illumination, energy consumption of LED is 25%-30% of HPS’. LED’s brightness can be quickly adjusted between 0-100% of the maximum[4], it will not affect the service life and can achieve a good energy saving effect. At the same time, LED has a long life and firm structure, and its start time is short[5], all these features make LED be preferred light source of tunnel lighting[6].

2. The architecture of the system
Tunnel lighting system requires to effectively monitor all of the LED lamps in the tunnel, it can remotely find fault and control the LED’s on, off and brightness at any time as requirement. The centralized monitoring approach will greatly ease the labor intensity of workers, reduce equipment consumption, and improve work efficiency, furthermore the system’s real-time shorten the time of fault finding and maintenance period, thus passive management can be changed to active management.

Figure 1. the control system

The figure 1 shows the components included in the control system, and then we simply explain each component.

1) Data acquisition module
   Equipments used in data acquisition module mainly include brightness detector, illumination detector, vehicle detector and outside weather detector, which are respectively used to collect the information of outside brightness, illumination inside the tunnel, traffic flow, wind speed and visibility.

2) RTU(Remote Terminal Unit)
   RTU is responsible for monitoring and controlling on-site signals. After the acquisition data received, RTU analysed these data, and then conveyed the processing results to monitoring centre, simultaneously adjusted the LED drive current through the node power control unit.

3) Remote monitoring centre
   The monitoring centre monitored all kinds of information within the tunnel, it received data from RTU, then saved them in the database, and according to the corresponding program output light-dimming value to RTU that controls the node control unit.

4) Node power control unit
   The unit received the light-dimming signal of RTU, then output PWM(Pulse-Width Modulation) signal of corresponding duty cycle to LED power.
5) Load current detection module
Adopted dual operational amplifiers to detect the load current of LED tunnel lamp and then determined the operating condition.

3. The specific implementation of the system

3.1. The introduction of operating mode
The system controlled the brightness of all the LED lamps in the tunnel by RTU. All of the tunnel lamps were connected into a complete control network through the communication cables, and some detectors were accessed in the network, such as vehicle detectors, outside brightness detectors, illumination detectors. The system could automatically track the real-time changes of outside brightness and traffic flow, and real-time dim all the LED tunnel lamps steplessly[4], and achieve real “on-demand lighting” and substantial energy savings.

![Figure 2. the illumination system](image)

The structure of the illumination system is shown in figure 2. In the system, every RTU controls one or several neighboring LED tunnel lamps[5], which were connected through CAN bus, and then cascaded to CAN bus network, which could communicate with monitoring centre and formed local area network. The tunnel local area network automatically adjusted the brightness of every LED lamp according to predetermined program based on actual traffic flow and environmental brightness, and it can be controlled by administrator. The monitoring centre can obtain and store the power consumption and working state information of every LED, and can turn on or turn off every LED lamp in the tunnel or steplessly adjust their brightness. The system monitored the running state of every lamp in the network through load current detection module, and it facilitated maintenance and repair. In order to wire conveniently, the tunnel entrance approach, the left side and right side of tunnel, can be formed separate subnet, and then be connected into the monitoring centre. When network interruption detected, each RTU adjusted the brightness of all the tunnel lamps to the maximum according to the original setting in order to ensure traffic safety.

3.2. Build tunnel simulation model
Since it is complicated to determine the dimming basis in real tunnel through actual test, so we choose LabVIEW software to analyze and calculate the tunnel parameters, and then use DIALux lighting design software to build the tunnel simulation model.

When analyzing the tunnel parameters in LabVIEW, the vehicle speed and traffic mode must be determined firstly, and then call the traffic flow and outside brightness information of actual measurement, then calculate the required illumination of tunnel entrance section, transitional section, middle section and exit section at different times according to highway tunnel ventilation and lighting specifications (JTJ 026.1-1999)[1]. Here, the brightness of entrance section and transitional section were adjusted according to outside brightness, and the brightness of middle section and exit section were adjusted according to traffic flow[6].

Here we give some data that were collected in the summer solstice, which show the average traffic flow and the outside brightness between 6:00-8:00 in the day. Import these data into the LabVIEW and then calculate the length and the illumination of each section. In table 1, we just list the calculation results of entrance section and the transition section.

| Time of Day | Traffic Flow (veh/h) | Outside Brightness (cd/m²) | Entrance section Illuminance (lux) | Transition section illuminance (Lux) |
|-------------|----------------------|-----------------------------|----------------------------------|-------------------------------------|
| 6:00-7:00   | 213                  | 179.3                       | 67.23                            | TR1:30.00 TR2:30.00 TR3:30.00      |
| 7:00-8:00   | 298                  | 731.6                       | 274.35                           | TR1:82.31 TR2:30.00 TR3:30.00      |
| 8:00-9:00   | 386                  | 1723.1                      | 653.31                           | TR1:195.99 TR2:65.33 TR3:30.00     |
| 9:00-10:00  | 493                  | 2873.9                      | 1138.71                          | TR1:341.61 TR2:113.87 TR3:39.85   |
| 10:00-11:00 | 576                  | 3965.4                      | 1623.70                          | TR1:487.11 TR2:162.37 TR3:56.82   |
| 11:00-12:00 | 478                  | 4865.8                      | 1916.29                          | TR1:574.89 TR2:191.63 TR3:67.07   |
| 12:00-13:00 | 493                  | 5503.6                      | 2202.61                          | TR1:660.78 TR2:220.26 TR3:77.09   |
| 13:00-14:00 | 638                  | 5833.7                      | 2446.43                          | TR1:733.93 TR2:244.64 TR3:85.62   |
| 14:00-15:00 | 617                  | 5839.9                      | 2429.46                          | TR1:728.84 TR2:242.95 TR3:85.03   |
| 15:00-16:00 | 652                  | 5521.5                      | 2327.84                          | TR1:698.35 TR2:232.78 TR3:81.47   |
| 16:00-17:00 | 618                  | 4895                        | 2037.15                          | TR1:611.15 TR2:203.71 TR3:71.30   |
| 17:00-18:00 | 600                  | 4004                        | 1654.84                          | TR1:496.45 TR2:165.49 TR3:57.92   |

In accordance with the calculated length and illuminance in different tunnel sections by LabVIEW, we determine the dimension of tunnel model in DIALux, and select the material and attribute of space components (mainly include the material and the reflectance of road surface, wall and ceiling), and then choose suitable LED lamp with desired power, and determine the layout mode of lamps, then set the calculation points on the working surface, at last calculate and generate report. According to the report and compared to the highway tunnel ventilation and lighting specifications (JTJ 026.1-1999), check whether the report result meet the specifications, if not, adjust the power or the layout mode of LED lamps. When simulating real-time adjustment of each section’s brightness, regulate the power of LED in the tunnel simulation model, and finally make the calculation results consistent with the lighting specifications. The dimming basis is just the illumination information of each section and the power of LED lamp in the simulation model.

At present the lighting brightness curves of most tunnels render step, furthermore when reducing the lighting level, as the lamps were light up alternately or every few, this will lead to the deterioration
of road surface illumination uniformity, and make the drivers feel visual fatigue, and even bring about security risk.

When simulating and calculating by DIALux, place the calculation points of the appropriate number, finally according the illumination values of each point in the calculated report, draw the illumination curve, which The illumination curve obtained according to DIALux shown in Figure 3. The outside brightness is 5000cd/m², traffic flow is 600 per hour, and the length of the tunnel is 600m.

![The illumination curve of tunnel from DIALux](image)

Figure 3. In the illumination curve, the x axis shows the numbers of the calculation points, and the y axis shows the illumination value.

The curve fits the demand of CIE illumination degression curve recommended by International Commission on Illumination. And using LED intelligent control system to dim light on-line and steplessly, we can not only reduce the lighting level but also keep the illumination uniformity in a good level, which also meet the physiological characteristics of human vision.

3.3. The features of the tunnel illumination system
The greatest feature of the system is that it can steplessly dim all of the LED lamps on-line between 0-100% of rated power. The system can either dim one lamp, and also can dim all the lamps simultaneously, it also can divide all the lamps into groups and then dim the different groups in different degrees, all these are important to tunnel energy-saving illumination. The system monitors on-line the working current of each lamp, when one lamp is broken or not working properly, the alarm will show in the monitoring centre and it will remind staff to maintenance and replacement. It can avoid the workers to inspect on the spot thus economize the human resources. We build the tunnel simulation model by DIALux lighting design software, which can not only simulate the real tunnel environment, and also calculate the illumination in the tunnel according to the selected lamps and the layout, which provide the basis for the dimming of the system.

4. The conclusion
The article describes the theory and the working methods of the tunnel illumination system, despite the relatively high cost of high-power LED lights, the enormous energy-saving effect and the well-behaved controllability is beyond compare to other lighting devices. This project is the key research topic of Zhejiang Jinji Electronics Co., Ltd. The system can ensure the safety of the drivers
without reducing the brightness within the tunnel, and it can produce good energy saving effect, this is also the main direction of the tunnel lighting.

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