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Research Article

Control the on-demand Lighting of Tunnel Based on PLC

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Abstract: The tunnel lighting should not only ensure the safety of the operation but also should realize lighting energy saving as far as possible. Analyze the control method of on-demand lighting for each lighting section. Adopt PLC programming to realize the real-time and on-demand lighting for threshold zone1. Achieve the purpose of safety and energy saving. Hope to provide reference for the research of highway tunnel lighting technology.
Keywords: tunnel lighting; plc; on-demand lighting; energy saving

INTRODUCTION

Tunnel lighting directly affects the operation safety and energy saving of tunnel and it is the biggest daily expenses in the tunnel operating expenses. How to achieve the goal of safe, comfortable and economic energy for tunnel lighting is an urgently problem to be solved.

The luminance out of the tunnel L20(S) is an important parameter for the lighting system. The setting of L20(S) to a large extent affects the engineering investment and electricity in operation. Lighting design is carried out in accordance with the maximum luminance out of the tunnel in summer noon. But the luminance out of the tunnel changes constantly as the change of seasons, weather and time in the actual operation. The Japanese Tokyo Bay's cross-harbor tunnel once has been made a detailed comparison in the design. Under the same situation in the speed and other conditions, such as L20(S) is set to 4000cd/m2 and 6000cd/m2, annual electricity consumption (kWh) can float within 30% [1]. If lighting is controlled by a single way in the actual operation and stick to open all the lamps and lanterns according to the corresponding model under the condition of the design traffic volume, the design speed, the design luminance out of the tunnel. It will be great waste of electricity. The brightness inside the tunnel should be adapted to the change of real-time traffic and real-time luminance out of the tunnel. Under the condition of safe driving, adjust the brightness of lamps and lanterns according to the traffic volume and the luminance out of the tunnel can achieve the goal of operation safety and energy saving.

The applicable lamps

High pressure sodium lamp, fluorescent lamp, LED lights, etc. are usually used in the current highway tunnel lighting. The start time of high pressure sodium lamp is so long and this is nature of the light source itself. Gas discharge light source from the start to the stability of optical radiation needs dozens of seconds to tens of minutes [2]. And the dimming range is very small that does not apply to the on-demand lighting control mode. The fluorescent lamp has low efficiency and prone to cause higher harmonic when dimming. It may cause interference to the power grid [3]. And the response time of LED lamp is only a few tens of nanoseconds. Lamps and lanterns get different illumination intensity instantly according to the provided different direct current in the rated range. Adjusting the brightness of the LED light by controlling

the output current of the power source of the LED lamps and lanterns can achieve the brightness control of 256 levels. The dimming range is wide and has many levels. This ensures a smooth transition for lighting dimming. It truly achieve automatic dimming and on-demand lighting and the tunnel lighting goals of safety and energy saving.

The realization method of the on-demand lighting THE CONTROL METHOD

In order to achieve on-demand lighting, the real-time hourly traffic volume and the real-time luminance out of the tunnel need to be obtained. Luminance meter needs to be installed in each lighting section in order to get the corresponding actual luminance values. Compare the measured real-time luminance values with the calculated real-time needed luminance values. If the measured real-time luminance value is greater than the calculated real-time needed luminance value, then lower one level luminance of lamps and lanterns. On the contrary, heighten one level luminance of lamps and lanterns. PLC can be programmed to control changes of the average output current through direct voltage signal of 0-5V. The luminance control of 256 levels for LED lamps can be achieved.

Sections of tunnel lighting can be divided into threshold zone 1, threshold zone 2, transition zone 1, transition zone 2, transition zone 3, interior zone, exit zone 1, exit zone 2.

Threshold zone

Threshold zone 1:

Eth1=Lth1'-Lth1. Eth1 is the difference value between the measured real-time luminance value and the real-time needed luminance value in this lighting section; Lth1' is the measured real-time luminance value in this lighting section; Calculate the reduction factor k of the luminance according to the measured hourly traffic volume N. Lth1 is the real-time needed luminance value calculated by the measured real-time luminance out of the tunnel and the reduction factor k. Accordance to the specification, as for non-optical long tunnel of the length of L > 500m and optical long tunnel of the length of L > 300m, the corresponding luminance of threshold zone 1 should be calculated by formulas Lth1 =k×L20(S)[1]. L20(S) is the luminance out of the tunnel（cd/m2）. Get the real-time luminance out of the tunnel by the luminance meter installed outside the tunnel portal. Reduction factor k of the threshold zone luminance evaluates by table

Table-1: reduction factor k of the threshold zone luminance

design hourly traffic volume N [veh/（h·ln）]		design speed vt (km/h)				
one-way traffic	two-way traffic	120 km/h	100 km/h	80 km/h	60 km/h	20~40 km/h
≥1200	≥650	0.070	0.045	0.035	0.022	0.012
≤350	≤180	0.050	0.035	0.025	0.015	0.010

Note: when the traffic volume adopts the intermediate value, take the value by using linear interpolation.

For the one-way traffic highway tunnel with design speed of 120 km/h:

- (1)When the measured hourly traffic volume N≥1200, k=0.070;
- (2)When 350≤N≤1200, k=0.05+（0.07-0.05）（N-350）/（1200-350）=0.05+0.02（N-350）/850;
- (3)When N≤350, k=0.050.

According to the above methods, for any design speed highway tunnel, the real-time needed luminance of threshold zone 1 Lth1 can be calculated by Lth1=k×L20(S). K can be obtained by real-time hourly traffic volume N given by monitoring center through calculating and seeking table. The luminance out of the tunnel L20 can be measured by the luminance meter installed outside the tunnel portal. Lth1' is the measured real-time luminance value in this lighting section. Lth1' minus Lth1 is equal to Eth1.

The control rule for lamps and lanterns of threshold zone 1:

- When Eth1＞0, if the measured real-time luminance value is greater than the real-time needed luminance value this moment, should lower one level luminance of LED lamps.
- When Eth1＝0, if the measured real-time luminance value is greater than the real-time needed luminance value this moment, keep the current luminance of LED lamps.
- When Eth1＜0, if the measured real-time luminance value is smaller than the real-time needed luminance value this moment, should heighten one level luminance of LED lamps.

Threshold zone 2:

Eth2＝Lth2’－Lth2. Due to Lth2 =0.5×k×L20(S)=0.5Lth1(cd/m2), then Eth2＝Lth2’－0.5Lth1. The control rule for LED lamps of threshold zone 2 is the same as threshold zone 1.

Transition zone

Transition zone 1: Ltr1 =0.15Lth1, Etr1＝Ltr1’－Ltr1＝Ltr1’－0.15Lth1.

Transition zone 2: Ltr2=0.05Lth1, Etr2＝Ltr2’－Ltr2＝Ltr2’－0.05Lth1.

Transition zone 3: Ltr3=0.02Lth1=cd/m2, Etr3＝Ltr3’－Ltr3＝Ltr3’－0.02Lth1.

The control rule for LED lamps of transition zone is the same as threshold zone 1.

Interior zone

For the one-way traffic highway tunnel with design speed of 120 km/h, the real-time needed luminance value of interior zone values according to the following rules:

- When N≥1200 veh /（h·ln）, the value of Lin is 10.0 cd/m2;
- When 350 veh /（h·ln）＜N＜1200 veh /（h·ln）, the value of Lin is 6.0 cd/m2;
- When N≤350 veh /（h·ln）, the value of Lin is 4.5 cd/m2.

Ein＝Lin’－Lin. Ein is the difference value between the measured real-time luminance value and the real-time needed luminance value in this lighting section; Lin’ is the measured real-time luminance value in this lighting section; Lth1 is the real-time needed luminance value calculated by the measured hourly traffic volume N.

- When Ein＞0, if the measured real-time luminance value is greater than the real-time needed luminance value this moment, should lower one level luminance of LED lamps.
- When Ein＝0, if the measured real-time luminance value is greater than the real-time needed luminance value this moment, keep the current luminance of LED lamps.
- When Ein＜0, if the measured real-time luminance value is smaller than the real-time needed luminance value this moment, should heighten one level luminance of LED lamps.

Exit zone

In a similar way, the luminance control of exit zone 1: according to the formula Lex1 =3×Lin, so Eex1＝Lex1’－Lex1＝Lex1’－3Lin.

The luminance control of exit zone 2: according to the formula Lex2 =5×Lin, so Eex2＝Lex2’－Lex2＝Lex2’－5Lin.

The control rule for LED lamps of exit zone is the same as interior zone.

The example of on-demand lighting for threshold zone 1 controlled by PLC.

The programming steps

The analog voltage signal controlled by Plc is DC 0-5V. Three test values as input: N, L20(S), Lth1’.

The first step, get the value of K by the known value of N. When N≥1200, k=0.070; When 350≤N≤1200, k=0.05+（0.07-0.05）（N-350）/（1200-350）=0.05+0.02（N-350）/850; When N≤350, k=0.050.

The second step, calculate Lth1 by the formula Lth1=k×L20(S).

The third step, Eth1=Lth1'-Lth1. If Eth1>0, analog voltage signal decreases 0.02 V; If Eth1=0, keep the analog voltage signal; If Eth1<0, analog voltage signal increases 0.02 V.

The fourth step, recycling procedure, the three test value is updated once per minute.

The program compiled from ABB software

```
    R_TRIG1(CLK :=TRUE);
IF R_TRIG1.Q THEN AO :=3;
END_IF;(* the output voltage takes 3*)
    IF N>=1200 THEN K :=0.07;
END_IF;
    IF 350<=N AND N<1200 THEN K :=0.05+0.02*(N-350)/850;
END_IF;
    IF N<=350 THEN K :=0.05;
END_IF;(* the first step *)
    L20S;
    Lth1 :=K*L20S;(* the second step *)
    Eth1 :=Lth_1-Lth1;
    IF Eth1>0 THEN AO :=AO-0.02;
END_IF;
    IF AO<3 THEN AO :=3;
END_IF;
    IF Eth1<0 THEN IF AO <= 4.98 THEN AO :=AO+0.02;
END_IF;END_IF;(* the third step *)
    LIN_TRAFO1( IN :=AO, IN_MIN :=-10, IN_MAX :=10, OUT_MIN :=0,
OUT_MAX :=27648);
    V_OUT :=REAL_TO_INT(LIN_TRAFO1.OUT);(* convert the output value to digital quantity*)
```

The simulation is shown in figure 1.

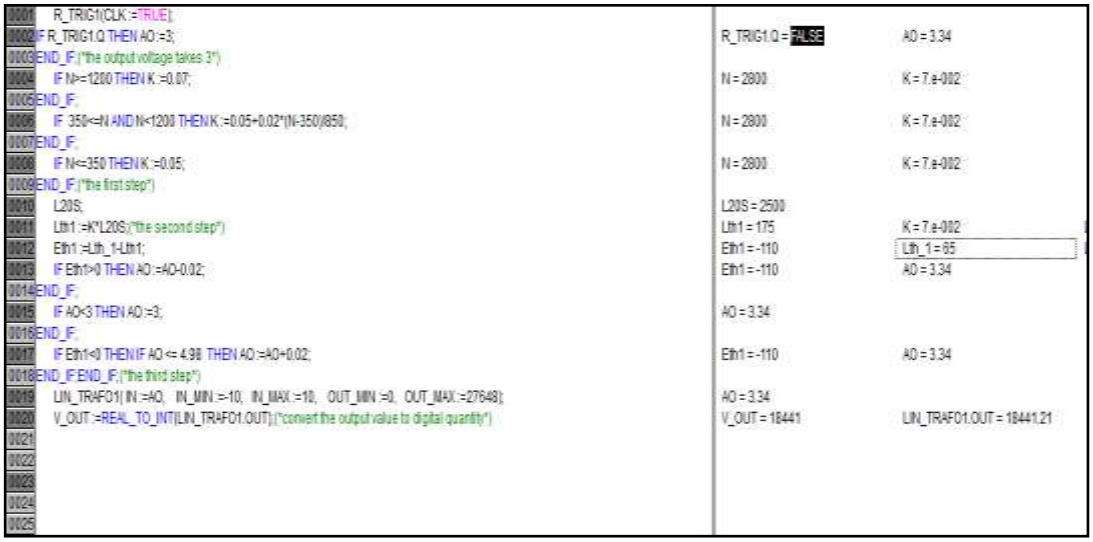

Fig-1: Simulation of the program

The PLC program of other lighting sections is similar to the program of threshold zone 1.

CONCLUSION AND RECOMMENDATION

With PLC control, tunnel lighting can achieve 256 levels adjustment of luminance, truly accomplish on-demand lighting and energy saving for tunnel lighting; Because the LED lamps work under low power condition in most of the time, it can prolong the life span of the LED lamps and power source and also reduce the luminance decrease of the LED lamps[4]. The system circuit is simple. The cost of the control box and cables can be saved. Therefore, the on-demand lighting technology of tunnel based on PLC control is applicable and worthy to spread.

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