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The Comparison of the Pulse and Constant-current LED Driving

Abstract. *The number of LED devices in lighting steady increases. More often, the user looks for lighting devices integrated with dimming functions. It causes the usage of the appropriate control circuits, built-in the lighting device. The article compares two control methods: popular PWM control and constant-current driving. The attention is given to energy efficiency and the interaction with living organisms of both mentioned methods.*

Streszczenie. *Liczba zastosowań LED w technice świetlnej stale rośnie. Coraz częściej użytkownikowi zależy na funkcji regulacji strumienia świetlnego emitowanego przez oprawę LED. Wymusza to stosowanie odpowiednich układów sterowania. Artykuł porównuje wybrane cechy dwóch metod: popularnej modulacji PWM oraz sterowania stałoprądowego. Zwrócono uwagę na efektywność energetyczną tych metod oraz ich interakcję z otoczeniem – żywymi organizmami.* ***(Porównanie impulsowej i stałoprądowej metody sterowania LED)***

Keywords: PWM LED driving, constant-current LED driving, LED dimming, control efficiency
Słowa kluczowe: sterowanie PWM, sterowanie stałoprądowe, regulacja jasności LED, sprawność sterowania

LED devices in lighting

One of the symptoms of increasing the energy–saving is the replacing classical lighting sources by modern devices using LED devices. LED in comparing with the classical bulbs have about five times greater lighting efficiency and many times greater lifetime. Great mechanical resistance and possibility of obtaining different colours open them the way to the ceilings of the world.

Lighting devices emitting the constant luminous flux are historically the first applications of LED in lighting. Now it is easy to buy LED-based devices for replacing the standard bulbs, used in household. But steady luminous flux of lighting device can be unsatisfactory for high-requirement user. Usually, he is looking for lighting devices with dimming ability. It is in accordance with two requirements:

- energy-saving realizing by reduction the illumination to some minimum sufficient value, according to the current circumstances, what causes less power consumption;
- esthetical needs, like the possibility of creation of different interior or exterior illuminations.

The dimming of classical light sources is well known, due to many years of it applications. In general it is based on the control of the supplying voltage. In the case of LED devices, which are strong nonlinear elements, the simply voltage control is not satisfactory – it is necessary to take into account two nonlinear relationships:

(1) $$I_F = f_1(U_F)$$

where I_F is the LED forward current

(2) $$\Phi = f_2(I_F)$$

describing the dependence between LED supplying voltage U_F and its luminous flux Φ. The practical realization of LED driving circuit with dimming ability depends on assumed rule of LED luminance control.

PWM technique has been used for LED dimming for many years. It is based on common methods of power control for some kind of electrical devices. But in LED applications PWM technique has some disadvantages, so new solutions for constant-current LED driving occurred few years ago. The article compares both mentioned method of LED driving.

LED driving circuits

LED is a semiconductor element working at low DC voltage. Because alternate current with much higher voltage is commonly used for supplying the electrical devices, it is needed to use additional circuits converting AC supplying to the low voltage directed current. Due to still too low for lighting applications luminance of single LED, it is necessary to build lighting devices containing many LEDs, working either at the same supplying voltage or current. Earlier used simply circuits with transformers and rectifiers are not applied now due to their disadvantages like: cost, mass, dimensions and possibility of stroboscopic effect. Today, the AC/DC converters are the most often used type of supplier. They are designed to obtain on their outputs voltages and currents needed to supplying group of LED [1]. In addition, the serial-parallel configurations of LEDs are matched to given application to obtain the best efficiency and fulfil the assumed requirements.

The supplying circuits of LED lighting device, which have to emit steady luminous flux, can be quite simply. It is designed mainly to reduce the energy losses and obtain needed supplying conditions – constant supplying current and voltage.

Some problems occur when the dimming possibility is needed. The solutions used for classical bulbs (phase AC control) are impossible for LED lamps, because AC/DC converters stabilize their outputs during the changes of AC parameters on inputs. The better solution is, for example, the usage of controlled AC/DC converters, which can change output voltage or current.

LED luminance control

The relations (1) and (2) show the possibilities of LED luminance control, using either voltage or current changes. The simplest solution is the serial potentiometer in LED supplying circuit, but it does not allow to automatic control of luminance and causes energy losses. According to this regulated suppliers and controllable AC/DC converters are more preferred in supplying LED lighting sources [1, 2]. The structure of these supplying devices usually allows to apply them as the actuators in control systems.

The next luminance control method is PWM modulation of constant supplying parameters. It allows to control the amount of energy flowing from supplier to the LED device, but it makes use of specific feature of human eyesight – its “integrating action” for light pulses. Such PWM LED control has to satisfy two conditions:

1. Forward LED current I_F should be less or equal nominal value I_{FN}, to avoid the damage of diode during the long-lasting work with maximum value of duty coefficient.
2. The frequency of PWM signal should so high to avoid the pulsing light effect. Usually the frequency at least 300Hz is used.

The usage of PWM modulation together with characteristic of human eyesight allow to obtain a simply method of LED luminance control. If at constant nominal forward current $I_F = I_{FN}$ the LED luminous flux is equal Φ_N, then the changes of duty coefficient D in the range $0 \le D \le 1$ (0..100%) allow to observe the changes of luminous flux Φ in the range $0 \le \Phi \le \Phi_N$. The relation between D and Φ is practically linear, so it means quite easy control of LED luminance without any feedback. The figure 1 shows the influence of duty coefficient D on observed luminous flux for exemplary white LED.

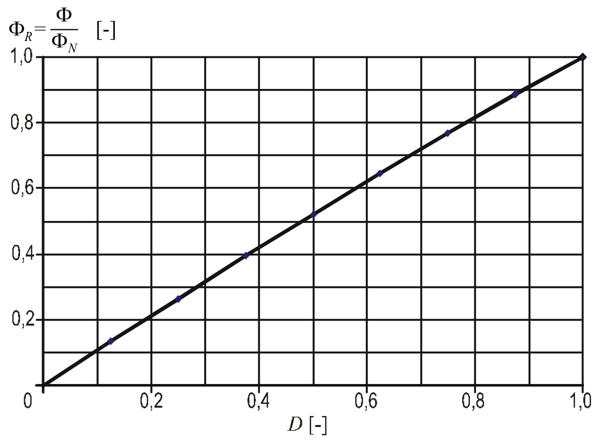

Fig. 1. Relative luminous flux Φ_R in relation to duty coefficient D in PWM luminance control

Described above controlling facility of observed luminance causes that PWM method has become very popular for several years. We can find on market many devices: specialized integrated circuits [3, 4, 5] or whole PWM controllers. There are also proposals of application PWM technique in FPGA structures [6], or in connection with microcontrollers [7]. In each case PWM LED driving applies semiconductor switching technique at not so low frequency.

The other LED luminance control technique has been taken into account in last years. The method is based on direct control of continuous forward current [8, 9, 10]. It is obtained by using regulated source current in LED supplying circuit – figure 2.

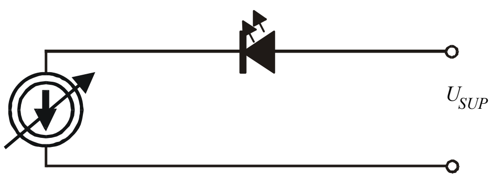

Fig. 2. The principle of constant current LED driving

The relation between the luminous flux Φ and LED current is nonlinear, but it has a LED-specific shape. It can be found after datasheet analyzing or appropriate measures (fig. 3). This specific nonlinearity is easy to approximation. In exemplary case approximating function (with 2% accuracy) between Φ_R and I_R is the following:

(3) $$\widehat{\Phi}_R = \sqrt{2}\ln(1 + I_R)$$

And function inverse to (3) is the following:

(4) $$\widehat{I}_R = e^{\frac{\Phi_R}{\sqrt{2}}} - 1$$

According to formulas (3) and (4) it is possible to realize open-loop system (without feedback) for obtaining needed values of LED luminous flux.

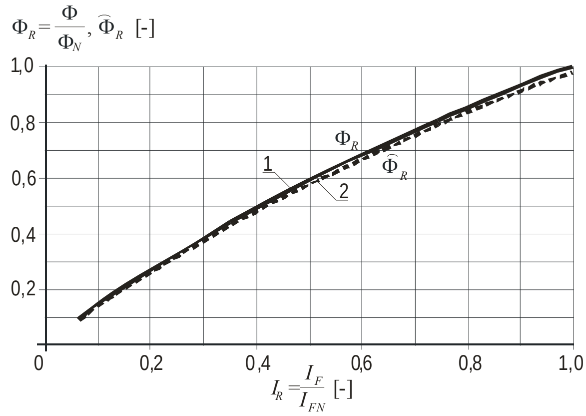

Fig. 3. Measured (1) and approximated (2) relation between LED relative luminous flux Φ_R and relative forward current I_R

The practical applicability of constant current technique can be also proved by increasing number of specialized integrated circuits offered by several manufacturers [3, 4, 5, 11]. Such ICs usually contains several current sources, with group else individual control. The maximum output current I_{MAX} of the sources is adjustable by single external resistor. The built-in digital serial interface allows to send to the chip correction coefficients to change temporary value of output current in the range $0 \le I \le I_{MAX}$. Because the full supervising of such IC driver is possible only using digital interface, the supervising microcontrollers becomes necessary [9, 10]. The additional advantages of these specialized chips are diagnostic functions like: over-temperature protection, short-circuit and break detection. These advantages in connection with supervising microcontroller allow to build very modern and advanced LED luminance controller.

Comparison of presented methods

One of the important features during comparing the different electrical devices is energy-saving. Comparing LED driving devices we should compare the amount of energy used for obtaining the same luminance.

Placing on the same diagram the curves of relations between luminous flux and constant current I_{RDC} (in constant-current method) and averaging current I_{RPWM} (in PWM method), we can see the differences (fig. 4). We can notice, that the same value of luminous flux Φ_R^* can be obtained at the lower value of constant-current I_{RDC}^* then averaging pulse current I_{RPWM}^*. It is especially visible at the values of luminous flux Φ^* from the range $0{,}2\Phi_N \le \Phi^* \le 0{,}8\Phi_N$.

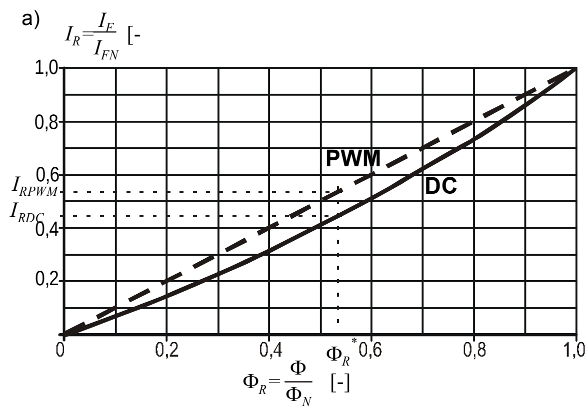

Fig. 4. The comparing of current consumption of PWM and constant-current methods at the same ordered luminous flux Φ_R^*

The difference between the values of both currents for the same luminous flux presents the figure 5. The visible on diagrams in figure 5 energy savings about 10% in the middle band of regulation range multiplied by the number of LED lighting devices can give meaningful global energy savings. So, it can be told, that luminance control by constant-current LED driving is more effective than PWM technique.

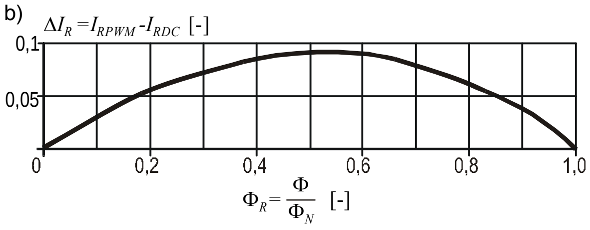

Fig. 5. The difference between needed average currents as function of ordered Φ_R

Comparing energy efficiency of both methods, energy losses in controlling circuits should be taken into account, too. In PWM control circuit we can find two kinds of energy losses:

1. Work losses ΔE_P in transistor switches, which can be approximated as product of: switched-on transistor current I_{FN}, transistor voltage drop ΔU_{TR} and the current value of duty coefficient D:

(5) $$\Delta E_P = I_{FN} \cdot \Delta U_{TR} \cdot D$$

   These losses are proportional to the value of duty coefficient D and become the highest at the maximum luminance of LED device. The losses can be reduced by selection the switching transistor with the lowest voltage drop.

2. Switching losses ΔE_K of transistor in transient states during switching, which are more difficult to approximation. Because duration of switching processes are constant, the value of switching losses ΔE_K depends mainly on frequency of PWM switching:

(6) $$\Delta E_K = f_{PWM} \cdot (\Delta E_{ON-OFF} + \Delta E_{OFF-ON})$$

   where: ΔE_{ON-OFF} means transistor losses during switch-off, and ΔE_{ON-OFF} – transistor losses during switch-on. The losses ΔE_K can be reduced by decreasing of switching frequency f_{PWM}, but this frequency cannot be decreased below some critical value (avoiding light pulsation).

In constant-current driving the main losses occur in the outputs of regulated current sources:

(7) $$\Delta E_{DC} = I_F \cdot (U_{SUP} - U_F)$$

These losses are proportional to the value of LED supplying current. They result from the need of some minimal value of voltage on current source output and the changes of LED forward voltage U_F (as function of I_F changes). The losses ΔE_{DC} can be reduced by appropriate supplying voltage U_{SUP} and serial-parallel connections of LEDs driven from the common current source.

The precise energy losses analyse in both compared methods can be subject of separate publication.

Both presented methods offer simple dependence between controlled parameter and received luminous flux. In PWM technique it is a linear function, and in constant-current one – easy approximated nonlinear function. These mathematical relations can be easy described in the software of microcontroller, which becomes the typical component of modern luminance control system.

During comparison of LED device luminance control method except economic aspects, like energy-saving, also functional quality should be taken into account. One of the elements of functional quality is the influence on human eyesight and environment. There is no discussion, that constant-current LED driving causes continuous luminous flux (like natural), observed by man, other living being, plants, electronic equipment, etc. In the case of PWM technique we have the sequence of strong light pulses, which are observed by our eyesight as a continuous light due to their frequency. We still do not know the real influence of long-lasting pulse lighting on our eyesight and especially on other living organisms.

Conclusions

Because LED lighting are more and more popular, the luminance control of such lighting sources becomes more important. The presented comparison of two the most popular solutions for LED luminance control does not point the better one. The PWM technique, which has been used for several years, seems to be easy applicable, but we do not know everything about its influence on the living environment. Constant-current driving, little more difficult in application, is probably more effective and safe for living environments. The research works and technology progress should give the answers to the mentioned above problems, in short time.

Presented results are the part of research work No S/WE/1/11

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