TEMPERATURE DEPENDENCE MODELING FOR POWERFUL LED CHARACTERISTICS IN MULTISIM

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ABSTRACT

The current models of light-emitting diodes describe only some characteristics and parameters, but do not allow to set their temperature dependences. Therefore, these models do not allow to study the processes occurring in real lamps and luminaires. The article considers the XT-E Royal Blue LED model developed in Multisim environment, which is manufactured by Cree, in which the dependence of its characteristics on the temperature of the semiconductor structure is implemented. The principles of the model creation are described. The results of ampere-voltage and emissive characteristics of a powerful LED modeling are presented at different values of its semiconductor structure temperature. The conclusions are made about the possibility of this model use to study the processes occurring in real LED lamps and luminaries.

Keywords: temperature dependence of characteristics, high-power LED, current-voltage characteristic, flux-current characteristic.

1. INTRODUCTION

The main trend of modern lighting technology development is the creation of energy-efficient LED light sources (LS). In order to increase the reliability of LED lamps and luminaires during their design, it is necessary to take into account the peculiarities of LED operation in different conditions and operating modes. To do this it is necessary to perform the mathematical modeling of electrical and thermal processes taking place in them at the design stage of LED LS. However, there are no mathematical models of LEDs nowadays, which allow to model processes taking place in real lamps and luminaires.

The existing models of light-emitting diodes describe their VAC only and do not allow to set its temperature dependence [1, 2]. It is required to develop the mathematical model of LED in Multisim environment, where VAC dependence on the temperature of its PS will be realized.

With the development of LED light sources, the need appeared to ensure their high reliability. LED manufacturers guarantee the service life of their devices up to 70,000 hours (8 years of continuous operation), however, this is the calculated value that is obtained for an individual LED. During the creation of LED lamps and lighting fixtures, LEDs are included in consecutive, parallel or consecutive-parallel groups [3, 4].

Due to the instability of the manufacturing process, the LEDs of one group have the variation of electrical and thermal parameter values and characteristics [5, 6]. The main electrical characteristic of a LED is its ampere-voltage characteristic (VAC). Figure-1 shows the possible variance of VAC for LEDs.

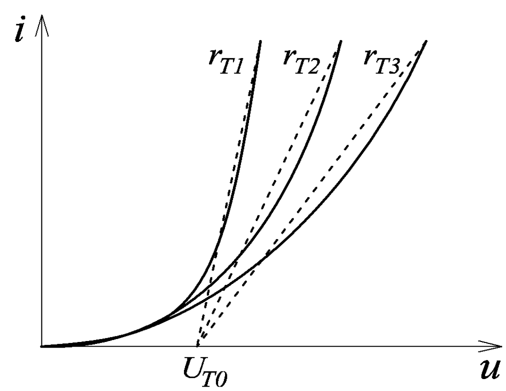

Figure-1. VAC of LEDs with the same values of direct voltage drop, but with different values of differential resistance.

LEDs with similar VAC (curve 1,2 and 3) have different values of electrical parameters [7, 8]. When you use such LEDs in one group, they will have different power, which will lead to unequal thermal modes of individual devices operation. The reliability of such lamps and luminaires is significantly reduced in comparison with the calculated values. To increase the reliability of such systems, it is necessary to study the processes taking place in them.

The most universal method to study LED lamps and luminaries is the mathematical modeling of electrical and thermal processes taking place in them. However, modern software products designed for electrical circuit modeling contain LED models that do not allow to take into account the variation of characteristics and the values of device parameters, as well as their temperature dependence, which significantly reduces the scope of these programs application [9, 10].

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In order to simulate real electrical and thermal processes in LED lamps and light fixtures, it is necessary to create an electric model of LED, which allows:
- to take into account the variation of its characteristics and parameter values, caused by the instability of production technological process;
- to take into account the temperature dependence of its characteristics and parameters;
- to simulate different types of LED group connection [11].

2. METHOD

a) Temperature dependence of ampere-voltage characteristic modeling

One of the best programs designed to model the processes occurring in electrical circuits is Multisim environment. Let's study the standard electric model of a LED that is offered in this environment.

The main electrical characteristic of a LED is its ampere-voltage characteristic (VAC) in the forward direction. Let's determine LEDs VAC in Multisim environment contained in a standard library. To do this, we will compile the circuit shown on Figure-2.

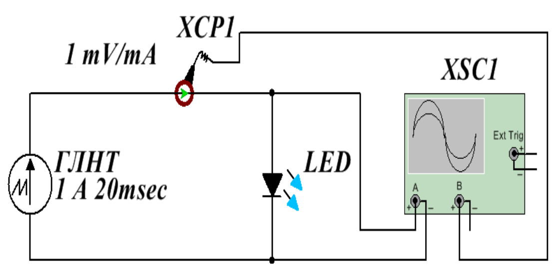

Figure-2. The circuit to study the direct LED VAC.

Figure-2 demonstrates the following notations: GLIC - generator of linearly increasing current; LED - LED model; XCP1 - current shunt; XSC1 - oscilloscope.

The principle of direct VAC determination of a light-emitting diode is the following one. A linearly increasing current from GLIC is fed to the developed model. In this case the current value flowing through a LED, which is fed to XSC1 is determined using XCP1. The direct voltage drop on a LED is also determined in XSC1 and a straight branch of its VAC is constructed.

Using the circuit shown on Figure-2, the direct VAC of blue, green, red, and yellow LED are determined, the models of which are offered in the Multisim environment, are determined. The simulation was performed at the temperature of the LED semiconductor structure (SS), equal to Tj = 27 ºC. This value of SS temperature is set automatically in the simulation environment, and it is not possible to change it. The maximum permissible operating current of LEDs is assumed to be 1 A.

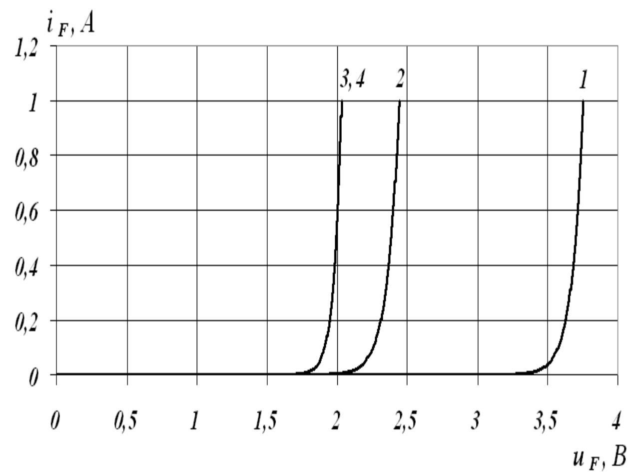

Figure-3. LEDs VAC: 1 — dark blue, 2 — green, 3, 4 — red, yellow.

Figure-3 shows that the value of the direct voltage drop on LEDs at direct current value i_F = 1 A is equal to: for blue one - u_F = 3.76 V; For green one - u_F = 2.44 V; for red and yellow one - u_F = 2.03 V.

The obtained results show that the LED model proposed in the Multisim environment has the electrical parameters and characteristics corresponding to the real ones. However, it does not realize the dependence of these parameters and characteristics on the temperature of the LED SS. On the basis of this model, the model of a light-emitting diode is developed, taking into account the temperature dependence of its parameters and characteristics.

The dependence of LED direct voltage drop value on the temperature of its SS describes the temperature coefficient of voltage (TCV), which is determined by the following formula:

$$TKH = \frac{\Delta U}{\Delta T_j} \tag{1}$$

where ΔU is the voltage change value; ΔT_j is the SS temperature change.

The change of direct voltage drop value on the LED at its SS temperature change is determined by the following formula:

$$\Delta U = TKH \cdot (T_j - T_{j0}) \tag{2}$$

where T_j is SS temperature, and T_{j0} is the initial SS temperature.

There is an electric LED model in Multisim environment. However, the temperature dependence of LED VAC is not taken account [4]. According to the existing model, taking into account the dependences (2), a LED electric model was developed, in which the influence

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of its SS temperature on VAC is described [5]. The appearance of the created model is shown on Figure-4.

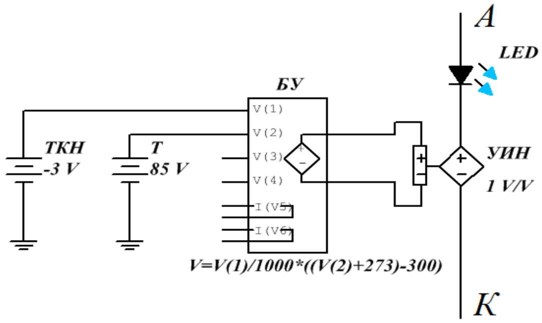

Figure-4. LED electric model.

The following notations are introduced in Figure-4:
TKN - voltage source, which sets TKN value in mV/ºC;
T - voltage source, which sets SS temperature in ºC;
CU - control unit;
CVS - controlled voltage source;
LED - the existing LED model;
A - the anode of the developed LED model;
K - the cathode of the developed LED model.

The principle of the proposed electric model operation is the following one. In order to implement the temperature dependence of LED VAC consequently with the existing LED model, the CVS is turned on which allows to increase or decrease the value of direct voltage drop, depending on SS temperature change. The value by which the value of the direct voltage drop varies is calculated in the CU according to the formula (2). The values of TKN and SS temperature are supplied to the CU from TKN and T voltage sources, respectively. The voltage of TKN source equal to 1 V corresponds to the TKN value of 1 mV/ºC. The voltage of the source T equal to 1 V, corresponds to the value of SS temperature at 1 ºC. In order to simulate the temperature dependence of the direct LED VAC the circuit is fabricated in Multisim environment shown on Figure-4.

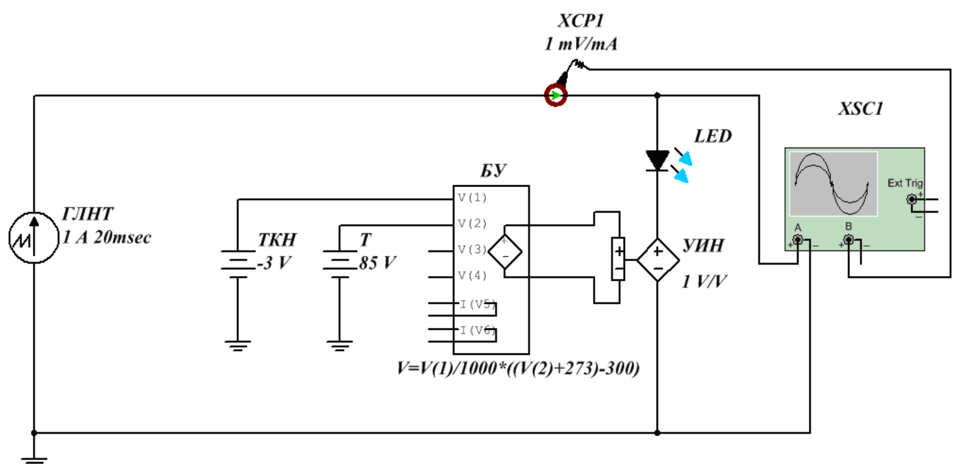

Figure-5. Circuit for LED VAC determination.

The following notations are introduced in this scheme:
GLIC - the generator of linearly increasing current;
XCP1 - current meter;
XSC1 - oscillograph.

The principle of LED VAC determination is the following one. The pulse of linearly increasing current is supplied on the developed model presented on Figure-4 within a given amplitude and duration. At that, the value of the current flowing through a LED, which is transferred to the input "B" of the oscilloscope XSC1 is determined using XCP1 meter. Besides, the voltage is supplied to the input "A" of the oscilloscope XSC1 applied to the LED in the forward direction. Next, the current dependence is determined in XSC1. The current flows through the LED (the signal from channel "B"), from the voltage on it (the signal from channel "A"), a straight branch of its VAC is designed and displayed on the oscilloscope screen.

b) Temperature dependence of radiative characteristic modeling

On the basis of the LED electric model described above the model is developed that takes into account its radiative characteristics.

The dependence of the relative radiation flux on the direct current value for XT-E Royal Blue LED, presented in its passport, is shown on Figure-6 [12].

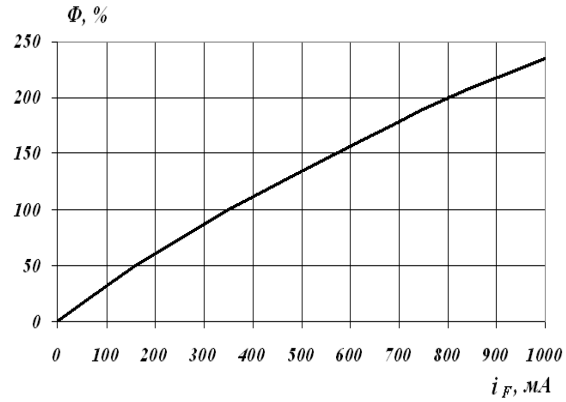

Figure-6. The dependence of relative radiation flux on the direct current value of XT-E royal blue LED.

According to Figure-6 the dependence of the relative radiation flux on the direct current of the LED under study is a nonlinear one. As it was mentioned above the radiation flux of the LED is Φ = 500 mW at the current of IF = 350 mA and SS temperature of 85 °C, which corresponds to 100% in relative units. On the basis of these data, it is possible to transfer any value of the relative radiation flux (Figure-8), expressed in percentage, into an absolute value expressed in mW.

In order to develop a LED model, taking into account the above-described requirements, it is necessary to obtain an analytical description of the relative radiation flux dependence on the direct current value. Since the LED emissivity is determined solely by radiation flux and direct current value measurement, it is possible to describe it using mathematical formulas by applying the approximation and further processing of results.

In order to obtain the mathematical description of the radiative characteristics in MS Excel environment, the dependence of the LED radiation flux on the direct current magnitude is presented and a polynomial trend line with the power value of 2 is developed. The obtained approximation results of this dependence are presented on Figure-7.

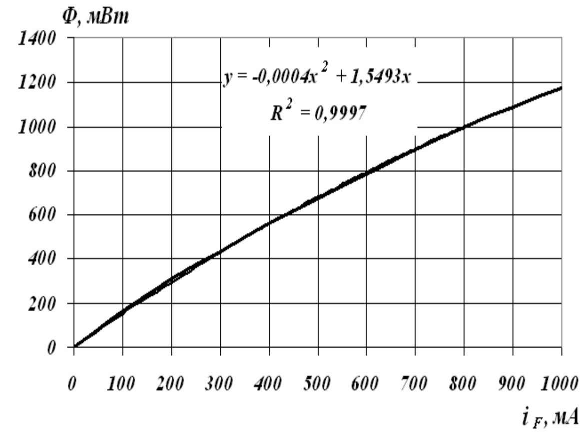

Figure-7. Dependence approximation results concerning the relative radiation flux on the direct current of XT-E royal blue LED.

Figure-7 shows that the required dependence of the relative radiation flux Φ on the LED direct current value i_F is described by the following expression:

$$F(i_F) = -0{,}0004 i_F^2 + 1{,}5493 i_F \qquad (3)$$

At that, the value of approximation reliability made R2 = 0.9997. This approximation reliability allows us to apply the expression (3) when you implement the radiative characteristics of XT-E Royal Blue LED model in Multisim environment.

Based on the obtained dependence (3) and the existing electric model of the LED in Multisim environment, the model was developed that makes it possible to realize the dependence of the relative radiation flux Φ on the value of the direct current iF. The principle of a model creation is similar to the principle described earlier.

Figure-8 shows the LED model developed in Multisim environment, and the diagram for its radiative characteristics modeling.

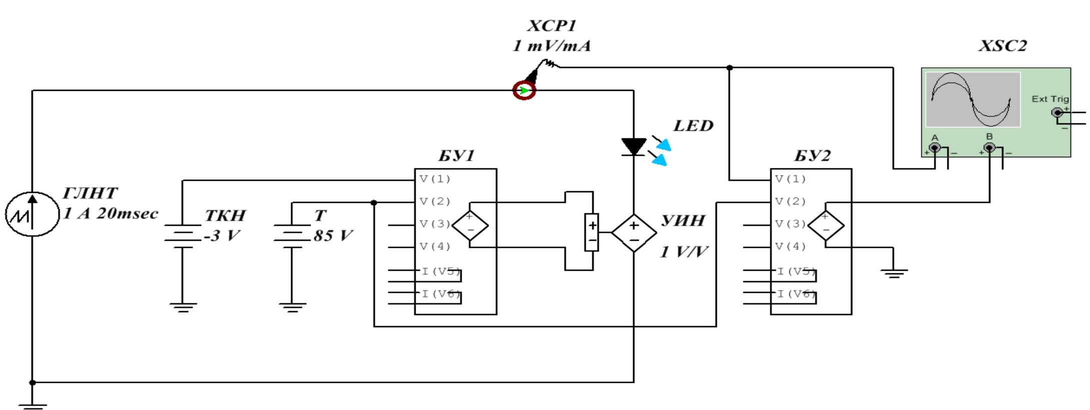

Figure-8. The circuit developed in Multisim environment to model the radiative characteristics of XT-E royal blue LED.

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Figure-8 introduces the following notation:
TKN - voltage source, which sets TKN value in mV/ºC;
T - voltage source, which sets SS temperature in ºC;
CU1 - control unit that realizes the temperature dependence of VAC;
CU2 - control unit that implements the radiative characteristic;
CVS - controlled voltage source;
LED - the existing LED model;
GLIC - the generator of linearly increasing current;
XCP1 - current meter;
XSC1 - oscilloscope.

In order to obtain the radiative characteristic, the signal is supplied from the current meter XCP1 to CU2, where the value of the radiation flux is calculated in accordance with (3). Then the signals are supplied to the XSC1 oscilloscope from XCP1 (direct current value i_F) and CU2 (the radiation flux value Φ), in which the emitting characteristic of XT-E Royal Blue LED is designed.

Using the circuit shown on Figure-10 they simulated the emissivity of the LED under study in Multisim environment. The results of dependence modeling of the relative radiation flux on the direct current value are compared with the LED passport data and are shown on Figure-9.

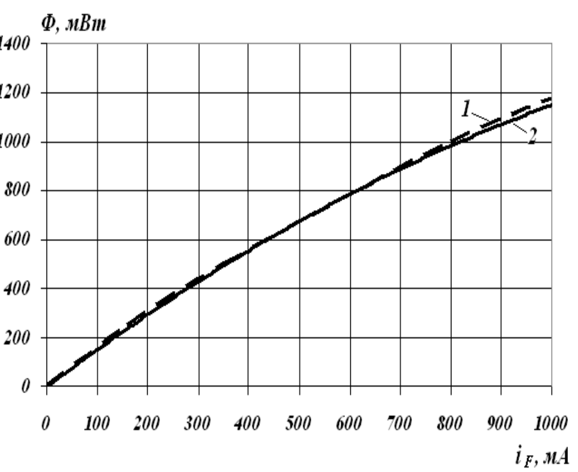

Figure-9. XT-E royal blue LED: паспорте; 2 —Multisim.

According to the information presented on Figure-9, we can conclude that the dependence obtained in Multisim environment coincides with the dependence presented in LED's passport almost completely. This indicates the adequacy of the applied approach and the model created on its basis.

Further, the dependence of radiation flux on the temperature of its SS is realized. The dependence of a relative radiation flux on the LED SS temperature value, presented in its passport, is shown on Figure-10.

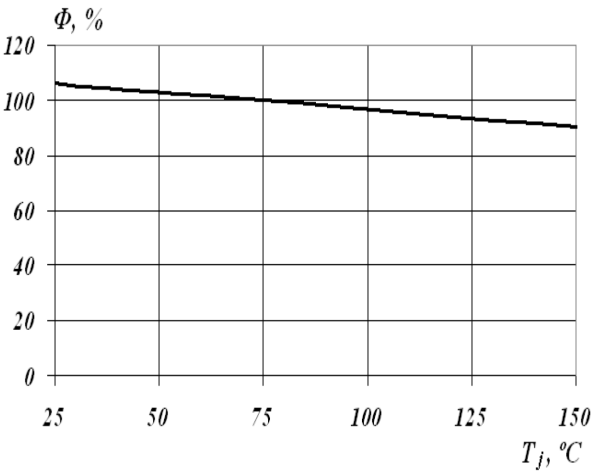

Figure-10. The dependence of the relative radiation flux on SS temperature value of XT-E royal blue LED.

According to Figure-10 the dependence of the relative radiation flux on SS temperature value of a light emitting diode is almost linear one. A relative radiation flux reaches its maximum value of 107% at SS temperature T_j = 25 °C. The minimum value of the relative radiation flux making 90% is observed at the value of T_j = 150 °C. Thus, during the increase of a light emitting diode PS temperature the value of its relative radiation flux decreases linearly.

It is required to obtain an analytical description of the realizable dependence. The dependence obtained by the experimental method is shown in LED passport (Figure-10). Therefore, it is possible to describe it using mathematical formulas by applying the approximation and further processing of results.

In order to obtain the mathematical description of the relative radiation flux Φ dependence on SS temperature value T_j of LED, it is displayed in MS Excel environment and a linear trend line is designed. The required dependence is obtained as the approximation result. This dependence is described by the following expression:

$$\Phi(T_j) = -0{,}1284 \cdot T_j + 109{,}37 \tag{4}$$

At that the value of the approximation reliability made R^2 = 0.9992. This approximation reliability makes it possible to apply the expression (4) when the dependence of the relative radiation flux on SS temperature of XT-E Royal Blue LED is realized in Multisim environment.

3. RESULTS

Using the developed model, they performed the study of VAC temperature dependence concerning the XT-E Royal Blue LED produced by Cree company. This LED has the following parameter values.

1. The maximum permissible operating current is 1 A.
2. The direct voltage drop (at the current of 1 A) makes 3.5 V.

3. TKN - 3 mV/ºC.
4. The maximum permissible SS temperature is 150 ºC.
5. The radiation flux makes 500 mW (at the current of IF = 350 mA and SS temperature T_J = 85 °C).

The simulation was carried out at the following SS temperature values of the LED:
- at room temperature T_j = 25 ° C;
- at operating temperature T_j = 85 ºC;
- at the maximum permissible temperature T_j = 150 ºC.

The obtained results of temperature dependence simulation for direct AVC of the LED are shown on Figure-11.

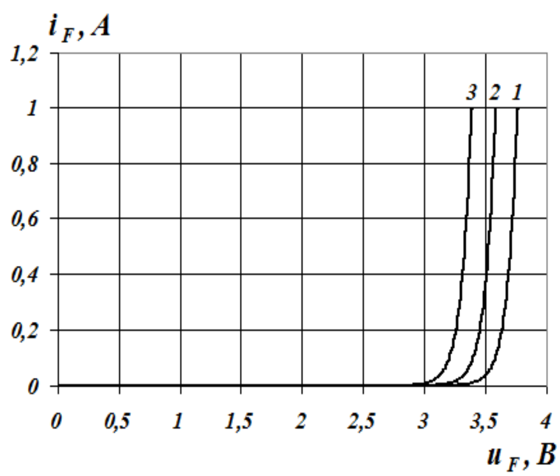

Figure-11. The VAC of XT-E royal blue LED at different temperatures of its SS: 1 — T_j = 25 ºC; 2 — T_j = 85 ºC; 3 — T_j = 150 ºC.

According to Figure-11 it is evident that the value of the LED direct voltage drop at the temperature of its SS T_j = 85 ºC and the direct current value i_F = 1 A was u_F = 3.58 V. When SS temperature of LED is increased from 25 ºC to 150 ºC its VAC is shifted to the left, since TKN has a negative sign. At that, the value of the direct voltage drop was reduced by 0.4 V.

The modeling of the studied LED emissivity at different values of its SS temperature is carried out. The following values of LED SS temperature were selected for modeling: room temperature T_j1 = 25 °C; working temperature T_j2 = 85 ºC; the maximum permissible temperature T_j3 = 150 ºC. The results of the relative radiation flux dependence modeling on the direct current value at different values of SS temperature are shown on Figure-12.

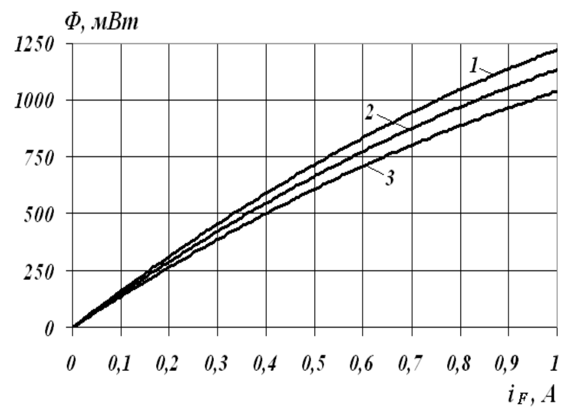

Figure-12. Radiation characteristic of XT-E royal blue LED for different temperatures of its SS: curve 1 - at T_j1 = 25 °C; Curve 2 - at T_j2 = 85 °C; Curve 3 - at T_j3 = 150 °C.

Figure-12 shows that when LED SS temperature is increased from 25 ºC to 150 ºC, its radiation characteristic shifts to the region of radiation flux lower values.

4. DISCUSSIONS

The LED model offered in Multisim environment has the electrical parameters and characteristics corresponding to the real ones. However, the dependence of these parameters and characteristics on the temperature of a light emitting diode is not realized in it, which imposes significant limitations on this model application area. Thus, in order to model real electrical and thermal processes taking place in LED lamps and luminaires, a light-emitting diode model was created that allows to take into account the influence of SS temperature on its parameters and characteristics.

The obtained results of modeling coincide with the data presented in the passport for the LED under study, which confirms the correctness of the developed model operation.

The conducted study showed that an effective LED operation demands that the temperature of its SS is as minimum as possible. In this case, the nominal value of the radiation flux is observed when the direct current value flowing through a LED is less than its nominal value. If the operating value of SS temperature T_j = 85 °C is exceeded, it is necessary to provide the direct current flowing through the LED to ensure the nominal radiation flux. This current value should be greater than the nominal value, which will lead to its additional heating and the need for a more efficient cooling.

5. CONCLUSIONS

In order to simulate real electrical and thermal processes in LED lamps and luminaires, a LED model is developed that allows:

- to take into account the variation of its characteristics and parameter values, caused by the instability of production technological process;

- to take into account the temperature dependence of its characteristics and parameters;
- to simulate different types of LED group connection.

It is supposed to use the developed model of LED to study the processes taking place in LED lamps and luminaires based on the group connection of LEDs. According to the obtained simulation results it will be possible to draw the conclusions about the efficiency and the reliability of an individual LED and a lamp or a light fixture in general.

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