Alternative diagnostic parameter for vehicle lighting products

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Abstract. The article is devoted to the justification of the use of the parameters of the transition thermal process in the technical diagnosis of vehicle lighting products.

1. Introduction
Currently, the operation of the electrical circuits of lighting products on a assembled vehicle is checked based on an analysis of the steady-state mode of operation of the electrical circuit: the current consumption is measured, the power is determined based on the voltage constant in the vehicle's on-board network, compared with the standard value determined by the technical conditions, and the results of this comparison give a conclusion on the technical condition of the tested product. However, this method of checking the operation has a significant drawback: the value of the diagnostic parameter (current consumption in steady state) is often determined for a group load, which includes lamps that are heterogeneous in power. In fact, such a functional check provides reliable information only about the state of the entire circuit (open or short circuit) [3,4,9,12].

In order to increase the reliability of checking the functioning of electrical circuits of lighting products of a car, we will consider the possibility of using alternative diagnostic parameters, namely, the use of transient parameters at the moment of switching on a lighting product [2,5,10,11].

2. Analysis of transition thermal process
To justify the use of the technical diagnosis of vehicle lighting products, as an alternative diagnostic parameter instantaneous value of current, at the initial moment of commutation of incandescent, it is necessary to analyze the thermal transition in the incandescent and put the theoretical dependence of the instantaneous current of its design parameters [6,7,8].

Consider the transition process in the vehicle incandescent with the following assumptions:
− heat removal from the filament is neglected (adiabatic process);
− believe that the specific heat is independent of temperature, a comparative analysis of this gives an error of not more than 5%.

Resistance of the filament:
\[ R(\vartheta) = \rho \frac{l}{S} ; \rho = \rho_0 (1 + \alpha \vartheta), \]

\( \vartheta \) - current temperature.

Incandescent current by Ohm's law:
\[ i(t) = \frac{U}{R(\vartheta)}, \quad (1) \]

\( U \) - board voltage, fixed in time.

The heat released in the incandescent due to the current flow:
\[ dQ = i^2(t)R(\vartheta)dt \]

Thermal state of the conductor:
\[ dQ = c\gamma S d\vartheta, \]

\( c \) - heat capacity of filament material; \( \gamma \) - the proportion of the material; \( l \) - the length of the filament; \( S \) - the filament section; \( d\vartheta \) - the temperature increment of the thread.

Heat balance:
\[ c\gamma S d\vartheta = i^2(t)R(\vartheta)dt \quad (2) \]

A similar problem is solved by thermal calculation of fuse elements. Solution of the problem is significantly simplified, since current fuse is specified by parameters of protected circuit. In this case, changing resistance of the filament determines its current [8,10].

In case (2) we divide variables:
\[ i^2(t) dt = c\gamma lS \frac{d\vartheta}{R(\vartheta)} \]

or
\[ \int i^2(t) dt = c\gamma lS \int \frac{d\vartheta}{R(\vartheta)}. \quad (3) \]

But, as the resistance is
\[ R(\vartheta) = \frac{l}{S} \rho_0 (1 + \alpha \vartheta) \quad (4) \]

the right side of the equation takes the following form
\[ c\gamma S \int \frac{d\vartheta}{R(\vartheta)} = c\gamma S^2 \rho_0 \int \frac{d\vartheta}{(1 + \alpha \vartheta)} = c\gamma S^2 \ln \frac{1}{A} (1 + \alpha \vartheta), \]

\( A \) - a constant.

Substituting into equation (3), we obtain
\[ \int i^2(t) dt = \frac{c\gamma S^2}{\alpha \rho_0} \ln \frac{1}{A} (1 + \alpha \vartheta) \Rightarrow -\frac{\alpha \rho_0}{c\gamma S^2} \int i^2(t) dt = \ln \frac{1}{A} (1 + \alpha \vartheta). \]

We use sequential transformations, properties of degrees and separation of variables [1]:
\[ \frac{1}{A} (1 + \alpha \vartheta) = e^{\frac{\alpha \rho_0}{c\gamma S^2} \int i^2(t) dt}. \]

signify \( \vartheta \):
\[ \vartheta = \frac{1}{\alpha} \left( e^{\frac{\alpha \rho_0}{c\gamma S^2} \int i^2(t) dt} - 1 \right). \]

By Ohm's law (1) and according to (4), we have
\[ i(t) = \frac{U}{R(\vartheta)} = \frac{US}{l \rho_0 (1 + \alpha \vartheta)} = \frac{US}{l \rho_0 A e^{\frac{\alpha \rho_0}{c\gamma S^2} \int i^2(t) dt}}. \]

Onwards:
\[
\frac{l_0 \rho_i A}{US} i(t) = e^{\frac{\alpha_{p_0}}{c \gamma S^2} \int i^3(t) dt},
\]
\[
\ln \left( \frac{l_0 \rho_i A}{US} i(t) \right) = -\frac{\alpha_{p_0}}{c \gamma S^2} \int i^3(t) dt,
\]
\[
-\frac{c \gamma S^2 i(t)}{\alpha_{p_0}} \ln \left( \frac{l_0 \rho_i A}{US} i(t) \right) = \int i^3(t) dt,
\]
\[
-\frac{c \gamma S^2}{\alpha_{p_0}} i'(t) = i^3(t).
\]
Thus:
\[
i'(t) = \frac{di(t)}{dt} = -\frac{\alpha_{p_0}}{c \gamma S^2} i^3(t).
\]
Using separation of variables, we obtain:
\[
-\frac{di(t)}{i^3(t)} = \frac{\alpha_{p_0}}{c \gamma S^2} dt;
\]
\[
-\int \frac{di(t)}{i^3(t)} = \int \frac{\alpha_{p_0}}{c \gamma S^2} dt;
\]
\[
\frac{1}{2i^2(t)} = \frac{\alpha_{p_0}}{c \gamma S^2} t + B,
\]
B – a constant.
Thus
\[
i^2(t) = \frac{1}{2 \left( \frac{\alpha_{p_0}}{c \gamma S^2} t + B \right)},
\]
and finally:
\[
i(t) = \pm \sqrt{\frac{1}{2 \left( \frac{\alpha_{p_0}}{c \gamma S^2} t + B \right)}}. \tag{5}
\]
We’ll find the constant B.
Let at \( t = t_1 \), \( i(t) = i(t_1) \), then (5) takes the following form
\[
i(t_1) = \pm \sqrt{\frac{1}{2 \left( \frac{\alpha_{p_0}}{c \gamma S^2} t_1 + B \right)}}.
\]
We perform basic algebraic calculations
\[
i^2(t_1) = \frac{1}{2 \left( \frac{\alpha_{p_0}}{c \gamma S^2} t_1 + B \right)}
\]
\[
\frac{\alpha_{p_0}}{c \gamma S^2} t_1 + B = \frac{1}{2i^2(t_1)}
\]
\[ B = \frac{1}{2I^2(t_i)} - \frac{\alpha \rho_0}{c\gamma s^2} t_i. \]

Substituting the found value \( B \) in (5)
\[
i(t) = \pm \sqrt{\frac{1}{2\frac{\alpha \rho_0}{c\gamma s^2} t + \frac{1}{2I^2(t_i)} - \frac{\alpha \rho_0}{c\gamma s^2} t_i}}.
\]
\[
i(t) = \pm \sqrt{\frac{1}{2\frac{\alpha \rho_0}{c\gamma s^2}(t-t_i) + \frac{1}{2I^2(t_i)}}}.
\]
\[
i(t) = \pm \sqrt{\frac{1}{\frac{2\alpha \rho_0}{c\gamma s^2}(t-t_i) + \frac{1}{I^2(t_i)}}}.
\]

Let \( t_i = 0 \), in this case \( \vartheta = \vartheta_{beg} \), then \( R(\vartheta_{beg}) = \frac{l\rho_0}{s}(1 + \alpha \vartheta_{beg}) \), \( i(t_i) = i(0) = \frac{U_s}{l\rho_0(1 + \alpha \vartheta_{beg})} \) and as a result we obtain
\[
i(t) = \frac{s}{\sqrt{\frac{2\alpha \rho_0}{c\gamma s^2} t + \frac{l^2 \rho_0^2(1 + \alpha \vartheta_{beg})^2}{U^2}}}.
\] (6)

This dependence (6) can be used to calculate the transient current in a real circuit. The validity of this expression with the assumptions can be considered within the time from power on to the establishment of the current.

Analyzing (6), we can make the following conclusions:
- the second term of the radicand in \( t = 0 \) specifies the initial value of the current \( i(0) \);
- the first term of the radicand specifies the transition thermal process;
- in general, the equation (6) allows us to estimate variations in characteristics of the incandescent when possible violation of its production, thus, to use the parameters of transient not only for diagnosis of the assembled vehicle, but also for the quality control of certain incandescent.

Let \( t_{ss} \) – to be a time, when \( \vartheta \) achieve the operating temperature of the filament (for wolfram it’s 2700°C). Then (6) transforms into
\[
I_{ss} = \frac{c\gamma}{2\alpha \rho_0} \left( \frac{s}{I_{ss}} - \frac{l^2 \rho_0^2(1 + \alpha \vartheta_{beg})^2}{U^2} \right).
\] (7)

Assuming that
\[ I_{ss} = \frac{P}{U} , \]

than (7) takes the form
\[
t_{ss} = \frac{c\gamma}{2\alpha \rho_0} \left( \frac{s^2 U^2}{P^2} - \frac{l^2 \rho_0^2(1 + \alpha \vartheta_{beg})^2}{U^2} \right).
\] (8)

In practice, the value \( t_{ss} \) expressed by (8) can be used to establish the time of the recording equipment (sweep duration, while the program calculate the parameters of the transition process, etc.).

We define the first derivative of the current at the time of commutation:
\[
\frac{di(t)}{dt}igg|_{t=0} = \frac{2\alpha \rho_0}{2c\gamma s^2} \left( \frac{Us}{l \rho_0 (1 + \alpha \delta_{beg})} \right)^3 = -\frac{\alpha \rho_0 U_s^3 s^3}{c\gamma s^5 l^2 \rho_0^3 (1 + \alpha \delta_{beg})^3} = -\frac{\alpha U_s^3 s}{c\gamma l^2 \rho_0^3 (1 + \alpha \delta_{beg})^3}.
\]

Dividing constants and design parameters of the incandescent, finally we obtain:

\[
\frac{di(t)}{dt}igg|_{t=0} = \frac{\alpha U_s^3}{c\gamma l^2 \rho_0^3 (1 + \alpha \delta_{beg})^3} \cdot \frac{s}{l^3}
\]

Thus, instantaneous value of current at the initiate moment of commutation of the incandescent might be used while diagnostic of vehicle lighting products as an alternative diagnostic parameter.

3. Conclusion

This equation \( i(t) = \frac{s}{\sqrt{\frac{2\alpha \rho_0}{c\gamma} l^2 \rho_0^3 (1 + \alpha \delta_{beg})^2} U_s^3} \) can be used to calculate the transient current in a real circuit. The validity of this expression with the assumptions can be considered within the time from power on to the establishment of the current. In general, the dependence allows us to estimate variations in characteristics of the incandescent when possible violation of its production, thus, to use the parameters of transient not only for diagnosis of the assembled vehicle, but also for the quality control of certain incandescent.

Instantaneous value of current at the initiate moment of commutation of the incandescent might be used while diagnostic of vehicle lighting products as an alternative diagnostic parameter.

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