Improving the safety of train lighting devices in curves

N O Frolov and E M Elkin
Ural State University of Railway Transport, 66, Kolmogorova street, Ekaterinburg, 620034, Russia

E-mail: NFrolov@usurt.ru

Abstract. The article presents a system for correcting the direction of the light beam of a rolling stock searchlight in curved sections of the track. The dependence of the angle of deviation of the axis of the light beam of the searchlight on the angle of inclination of the trolley is determined. The principle of correction of the light beam of a rolling stock searchlight using a matrix LED searchlight is described.

1. A method for correction the light beam of a rolling stock searchlight in curves

The searchlight of railway traction rolling stock is designed to ensure the safety of transportation when driving at night, in tunnels, as well as when driving in adverse weather conditions by lighting the railway track and the contact wire.

The disadvantage of this system is that it is not able to ensure safety when the train is moving in curved sections of the track, since in this case proper lighting of the track and the contact wire is not provided, which can lead to an accident [1].

It should be noted that the curved sections of the track make up a significant proportion of the total length of railways. At the same time, the tendency to reduce the quality of illumination of the curve increases with an increase in its radius.

Developments in the field of lighting of curved sections of the track are described in Russian patents [2, 3], however, they have a number of significant drawbacks, and therefore they have not been put into operation.

The method proposed in the patent [2] has a design with unsatisfactory overall characteristics, a lot of kinematic connections (due to the distance of the pin from the nose of the train), which slows down its reaction to changes in the curvature of the track. It is also worth noting that the implementation of this system on modern trains is technically impossible due to lack of space.

In turn, the main advantages of the adaptive control system for the head lighting of rolling stock [3] are the use of machine vision to control the searchlight. During operation, the glass behind which the sensors are located will inevitably become dirty, which will eventually lead to incorrect operation of the system and require frequent maintenance. In addition, in conditions of limited visibility, the use of this system is problematic.

In curved sections of the track, the elevation of the outer rail over the inner rail is used to dampen the transverse acceleration. When passing a curved section of the track, the crew part of the rolling stock will be inclined by a certain angle $\alpha$, depending on the height of the outer rail. The position of the crew part when passing the curve is shown in figure 1.
The calculation of the height of the outer rail $h$ is made according to the expression 1 [4].

$$h = k \cdot \frac{\frac{12.5 \cdot v_{av}^2}{R}}{h}, \quad (1)$$

where $v_{av}^2$ – the weighted average square speed, km/h; $R$ – the radius of the curve, m; $k$ – the coefficient of increase in the elevation of the outer rail, considering the displacement of the center of gravity of the crew to the outer side with respect to the axis of the curve, assumed to be equal to 1.0 at speeds up to 140 km/h inclusive and 1.2 at speeds of more than 140 km/h.

After expressing the radius of the curve, the expression (1) takes the form represented in the expression 2.

$$R = k \cdot \frac{12.5 \cdot v_{av}^2}{h}. \quad (2)$$

The number 12.5 in expressions (1, 2) is defined as follows (expression 3).

$$\frac{L_c}{g \cdot 3.6^2} \approx 12.5. \quad (3)$$

where $L_c$ – the distance between the centers of the rails, mm; $g$ – the acceleration of gravity, m·s$^{-2}$.

Considering the expression (3), the expression (2) takes the following form (expression 4).

$$R = k \cdot \frac{1590 \cdot v_{av}^2}{g \cdot 3.6^2 \cdot h}. \quad (4)$$

It can be seen from Figure 1 that geometrically the elevation of the outer rail is determined by the following expression.

$$h = \sin \alpha \cdot L_c. \quad (5)$$

After substituting expression 5 into expression 4, expression 6 was obtained.

$$R = k \cdot \frac{v_{av}^2}{g \cdot 3.6^2 \cdot \sin \alpha}. \quad (6)$$

At this stage, the dependence of the radius of the curve on the angle of inclination of the crew part in the curve is obtained, which is necessary for further calculation of the angle of rotation of the searchlight.

The next step is to determine the expression describing the required angle of rotation of the axis of the light flux of the searchlight (expression 7).

$$\beta = \arcsin \left( \frac{L}{2R} \right). \quad (7)$$

where $L$ – the range of the searchlight, m; $R$ – the radius of the curve, m.

Expression 7 is determined from the schematic representation of the rotation of the axis of the light flux of the searchlight in the curve (figure 2).
To determine the range of the searchlight, we schematically represent the operation of the searchlight (figure 3).

According to figure 3, the range of the searchlight \( L \) is determined according to the expression 8.

\[
L = \frac{H}{\tan(0.5 \cdot \gamma)}
\]  

(8)

Substituting expression (6) and (8) into expression (7), expression 9 is obtained [6].

\[
\beta = \arcsin \left( \frac{H}{\tan(0.5 \cdot \gamma)} \left( \frac{2 \cdot k \cdot v_{av}^2}{g \cdot 3.6 \cdot \sin \alpha} \right)^{-1} \right)
\]  

(9)

As a result, an expression describing the required angle of rotation of the searchlight axis depending on the angle of inclination of the crew in the curve is obtained.

The essence of the proposed method for correcting the direction of the searchlight's luminous flux in curves is as follows: an inclinometer mounted on the horizontal surface of the carriage part of the train and being a sensor determines the angle of inclination of the crew when passing the curve. The data is transmitted to the computing unit, in which, according to the previously defined expression (9), the angle of deviation of the axis of the light flux of the searchlight is calculated. Then the control signal is applied to the matrix LED spotlight, which is an executive element.

The use of a matrix LED spotlight due to its optical structure allows you to change the direction of the light flux without using movable elements in the design. The principle of operation of such a searchlight is as follows: each LED of the matrix searchlight acts as a kind of pixel, and the illuminated
area in front of the locomotive is a screen on which the light of all LEDs falls. By turning on and off each individual LED, you can control the zones of the illuminated space, which allows you to illuminate curved sections of the path. [7]

Graphically, the principle of operation is shown in figure 4.

![Graphical representation of the principle of operation of the matrix searchlight.](image)

**Figure 4.** The principle of operation of the matrix searchlight.

Only the LEDs of the main working area are constantly working (this zone corresponds to the zero value of the angle of deviation of the axis of the luminous flux (figure 4)), which provide illumination of the space when moving along straight sections. When moving in curves, the LEDs of the right or left working area are activated, providing a deviation of the axis of the light flux of the spotlight depending on the direction of rotation according to the expression (9). The oppositely located LEDs are switched off at this moment.

Thus, the problem of ensuring the safety of lighting the curved sections of the track in the dark was raised. A method is proposed and mathematically described for changing the angle of deviation of the axis of the searchlight's luminous flux depending on the elevation of the outer rail in the curved sections of the track, which provides optimal illumination of the curved sections of the track by the searchlight.

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