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Lighting device parameters influence on signal circuit safety in interlocking systems

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ABSTRACT
Signal circuits are an important part of the interlocking system. The main role of the signalling circuit is to switch the required signal aspects and signal checking. A signal is an interface between the interlocking system and a driver of the railway vehicle. Light bulbs are mostly used as a light source in most types of interlocking systems. It is possible to think about alternative light sources within the context of modernisation of the interlocking systems. The use of alternative light sources using must not cause signal circuit safety degradation. The article deals with problems of light bulbs replacement for another light source in AŽD 71 type relay interlocking in the Railways of Slovak Republic.

KEYWORDS: signal circuit safety, interlocking system, colour light signal, alternative light sources

1. Introduction

Relay interlocking systems were built for train control at railway stations in Czech and Slovak railway circumstances between 70-ties and 90-ties of the last century. AŽD 71 type relay interlocking systems were mainly used at railway stations on main lines. This type of interlocking equipment was produced and installed by the Czechoslovak company Automatizácia železničnej dopravy (Automation of Railway Transport), now called AŽD Prague. Many railway stations are now controlled by this system in Slovak railways.

AŽD 71 type relay interlocking system is based on the technique of own safety on failure – fail safe. NMŠ type relays are used as a basic construction component in this system. This type of relay belongs to the safety relays group. All safety relevant functions of this signal box are realised and checked by a part called an executive group based on this type of relays.

Signal circuits are very important part of the executive group. The main function of these circuits is to switch on individual signal lamps to create necessary signal aspects and to check lighting of them. In the case of any malfunction the signal has to light on a less allowing signal.

Management of Railways of the Slovak Republic considers an idea to replace signal bulbs used as a light source in colour light signals by other energy-saving light sources. Parameters of new signal lamps must not make the safety of signal circuits worse.

2. Signal circuit of AŽD 71

A schematic representation of the signal circuit used in AŽD 71 system is shown in Figure 1. The signal circuit consists of OM-2-60 type supervisory light relay (*xS*), fuse (*F*), ST-3/R type signal transformer (*Tr*), signal bulb 12 Volt / 20 watt, limiting rezistor 100 Ω (*R*), wires and a connecting cable between the signal box and light signal.

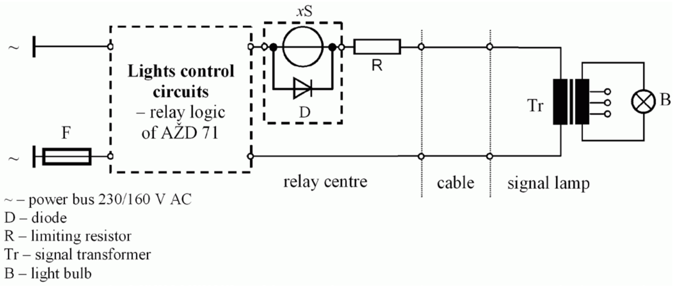


Fig. 1. Electrical scheme of signal circuit
Source: [3]

The circuit is powered by AC voltage 230 V/50 Hz in a daytime lightning routine or 160 V / 50 Hz in a night lightning routine.

The scheme shown in Figure 1 is identical for all signal lights on a signal device. The dashed line block represents control circuits for individual lights.

Signal aspects shown on a signal device are defined by signal rules of ŽSR [1]. In general a signal aspect can consist of one or more colour continuously or intermittently lighting lights. In the case of intermittent light the system can use slow flashing with a blink frequency of 0.9 Hz (54 cycles per minute) or quick flashing with a blink frequency of 1.8 Hz (108 cycles per minute) [2].

2.1. Signal circuit states

The following situation is considered to be the basic operating state: a signal lamp is without failure, the circuit is powered by nominal power voltage specified for the daytime or night light mode of signal lights. The work current flows in the circuit, the signal bulb is on and the circuit current controls the light relay attraction. The relay operation indicates lighting of the signal light. The following situations are considered failure states:

a) the signal light does not light, but the supervisory light relay operates (relay armature up) and indicates lighting of the light;
b) the signal light is flashing without command to flash and the supervisory light relay indicates a steady light;
c) the signal light is flashing or lights steadily, but the supervisory relay is released and so indicates a lightless state of signal.

The failure state according to point a) is potentially unsafe state. It is a possible situation in which a more allowing aspect is on the signal than informed by the feedback circuit. A similar situation is in the failure state according to point b) – flashing lights can be interpreted as a more allowing aspect.

The design of signal circuits in AŽD 71 type relay interlocking gives a possibility to react to the state according to point c). This state is not unsafe then.

The origination of a failure state is influenced by several factors – an important factor is the length of supply cable wire. A cross capacitance and longitudinal impedance are characteristic parameters of the cable. In the case of cables used in signal circuits we can transform the longitudinal impedance to longitudinal resistance. The cross capacitance and longitudinal resistance of the supply cable vary with increasing length of the cable. It is necessary to evaluate the maximum possible length of the supply cable. Standard [3] evaluates this length as 4 km. If the length of cables exceeds this value, the following failure states can occur:

- A signal bulb filament will burn, but the length of supply cable is too long, so the parasitic capacitance of the cable has a value sufficient for the circuit current to hold on the light relay armature up. So the signal bulb does not light, but the light relay signals that it does.
- At the end of signal circuit (e.g. primary or secondary winding of signal transformer, lamp-socket …) a short circuit will occur. In normal circumstances the fuse (*F*) at the power end of the circuit should be broken. But if the supply cable is too long, the longitudinal resistance of cable reduces the current value and the fuse will remain without any reaction. And again – the signal bulb does not light, but the light relay signals a correct state.

3. Bulbs replacement

There are more practical reasons to replace the older construction of signal lamps which uses bulbs as a light source:

- interlocking system modernisation,
- energy consumption decreasing,
- signal lamps life extension,
- signal lamps optical parameters improvement,
- maintenance reduction.

Modern interlocking systems often use the light emitting diodes (LED) as a light source in signal lamps. The main advantage of LEDs compared to bulbs is the energy saving and a longer life. The volt-ampere characteristic of LEDs is different from the V-A characteristic of a signal bulb. It is possible to design a circuit using LEDs which will simulate the V-A characteristic of a signal bulb. The advantage of this solution is a simple replacement of a bulb by an LED lamp. In this case no modifications to the signal circuit are necessary. The main disadvantage of this solution is the elimination of one of two LEDs advantages – energy saving.

Another possibility is to use a lamp with a different characteristic; this solution requires the signal circuit modification. One of many reasons for this modification can be a different method of LEDs lamp lighting checking. These modifications of signal circuits are more expensive than the way mentioned above.

The basic difference of lamp using LEDs is the fact, that an LED lamp needs an additional electronic circuit, which will simulate bulb properties. This circuit has to be powered. Because individual powering is impossible, additional circuits will use the energy dedicated to bulb powering.

The safety of signal circuit is based on reliable detection of non-luminous state of the signal lamp. In the case of any failure in an LED lamp the energy consumption of electronic circuits in the lamp must be low enough. The current via this circuit must not lead to the signal light relay operation – this is the condition for a safe reaction of relay to non-luminance state of the lamp. The electronic control circuit in an LED lamp has to be able to fully turn off all LEDs in the case of a defined number of LEDs failure or of the LED control circuit failure. An acceptable number of non-luminous diodes has to be defined in accordance with the signal lamp optical properties. Otherwise it is possible to have an ambiguous identification of signal aspect by the driver.

Full turning off and limiting of maximal current are functions which have to be realised with defined safety level; otherwise the safety of the signal circuit is reduced.

4. Analysis of lamp replacement effect on signal circuit

In the case of implementing functions described above with a defined safety level, it is necessary to define the maximal acceptable current level flowing in the circuit in the non-luminous state of lamp. In ideal circumstances the current should be 0 A. In reality, the current must cover the energy consumption of electronic control circuits of the signal lamp. The analysis should show, if the LED lamp has the same influence on the signal circuit as the original bulb.

Verification of the influence on circuit properties of safe reaction of signal light relay to expected lamp failures can be realised using a computer simulation or practical measurement.

4.1. Circuit simulation

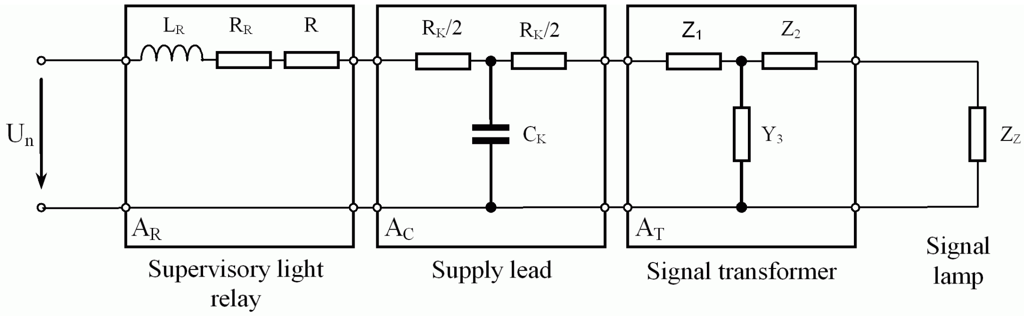
For simulation of the light relay response to the current flowing in the circuit we can use a model based on cascade matrixes. The cascade matrixes model the transmission properties of particular components of the circuit. We can substitute each component of the circuit by an equivalent circuit which represents the electrical properties of the component.

Supervisory light relay can be substituted by a coil representing serial connected winding inductance (L_R), winding resistance (R_R) and limiting resistor (R).

Supply conductors can be substituted by equivalent T-network which represents the primary parameters of line wiring (R_K – longitudinal resistance of cable, C_K – leakage capacitance of cable). The signal transformer can be substituted by equivalent T-network with different coefficient meaning – T-network of the transformer represents primary winding impedance (Z_1), secondary winding impedance (Z_2), leakage reactance and iron loss (Y_3).

The signal bulb or LED lamp can be substituted by a resistor which represents their input impedance (Z_Z). Fig. 2 shows the equivalent scheme of the signal circuit.

It is possible to compute values of cascade matrix for each component of the equivalent scheme. The computed values can be used then in the simulation of circuit. The values of current flowing through the winding of signal light relay are key values for the assessment of failures influences on the signal circuit safety. From this point of view



U_n – power voltage
A_R – cascade matrix of relay
A_C – cascade matrix of cable
A_T – cascade matrix of signal transformer

Fig. 2. Equivalent scheme of the signal circuit
Source: [own work]

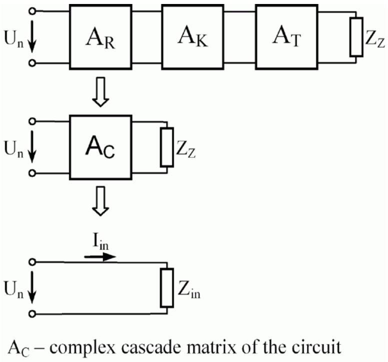


Fig. 3. Transformation of cascade matrixes
Source: [own work]

it is possible to transform the equivalent scheme shown in Fig. 2 to the common cascade matrix (AC). For this matrix we can compute the input impedance (Z_{in}). When we connect power voltage U_n to this impedance the current flowing through this impedance is the same as the current through the relay winding. [4]

The progress of cascade matrixes transformation is shown by Figure 3.

The software suitable for simulation of services and failure conditions is MATLAB (MATrix LABoratory). MATLAB is a programme which allows matrix computing, modelling and circuits simulations.

4.2. Circuit measurement

The influence of current flowing in a signal lamp on signal light relay operation can be examined by measurement. The measurement gives us a possibility to use real components of the signal circuit with the exception of supply conductors. The cables length affects correct operation of the circuit as indicated above (see chapter 2). It is very complicated to use a full length of cable in laboratory circumstances. For these reasons we use simulations of supply conductors by equivalent T-network.

Figure 4 shows the scheme suitable for measurement and analysis. The figure depicts a possible substitution of signal bulb by an LED lamp. Failures of the LED lamp were simulated by a potentiometer because it was impossible to induce failure state of the LED lamp during measurement.

5. Results analysis

For analysis acceptance it is necessary to set the most unfavourable conditions. These conditions can be as follows:

- Because of a failure the LED signal has moved to a non-luminous state, but the current consumed by electronic circuits of the lamp is flowing through the circuit. The state is more unsafe than a failure state after turning on, the signal will not move to the luminous state. The current necessary for the signal relay operation is higher than the relay release current.
- The supply voltage of signal circuit is maximal. As the maximal we can consider the voltage for daytime supply mode increased by 10% tolerance.
- The load is connected to signal transformer terminals on which the current through the secondary transformer winding will have the most unfavourable effect to relay release.

If in these conditions the signal light relay will not release, the failure state can be considered to be an unsafe state. If in these conditions the relay releases, the state is safe.

Figure 5 shows the results of analysis under the mentioned conditions. The curves show the current flowing in signal light relay winding versus the power lead length. The black curves (the lower group of curves) represent the current via relay in the failure state – filament broken. The grey curves (the upper group of curves) represent the current via relay in the failure state of LED lamp in circumstances that the electronic control circuits of LED lamp consume maximum 150 mA. The graph shows the signal light relay release current value too.

As a limit length of the power leads we can assume the length, where the current via the relay is below the relay

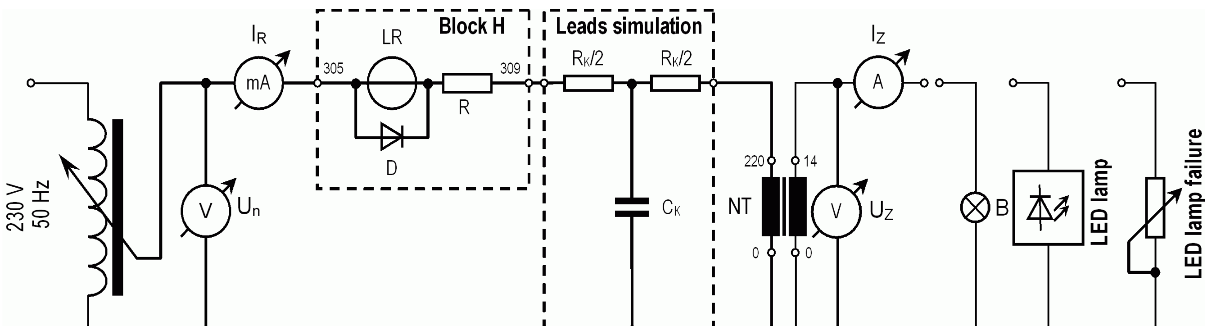


Fig. 4. The scheme used during measurement
Source: [own work]

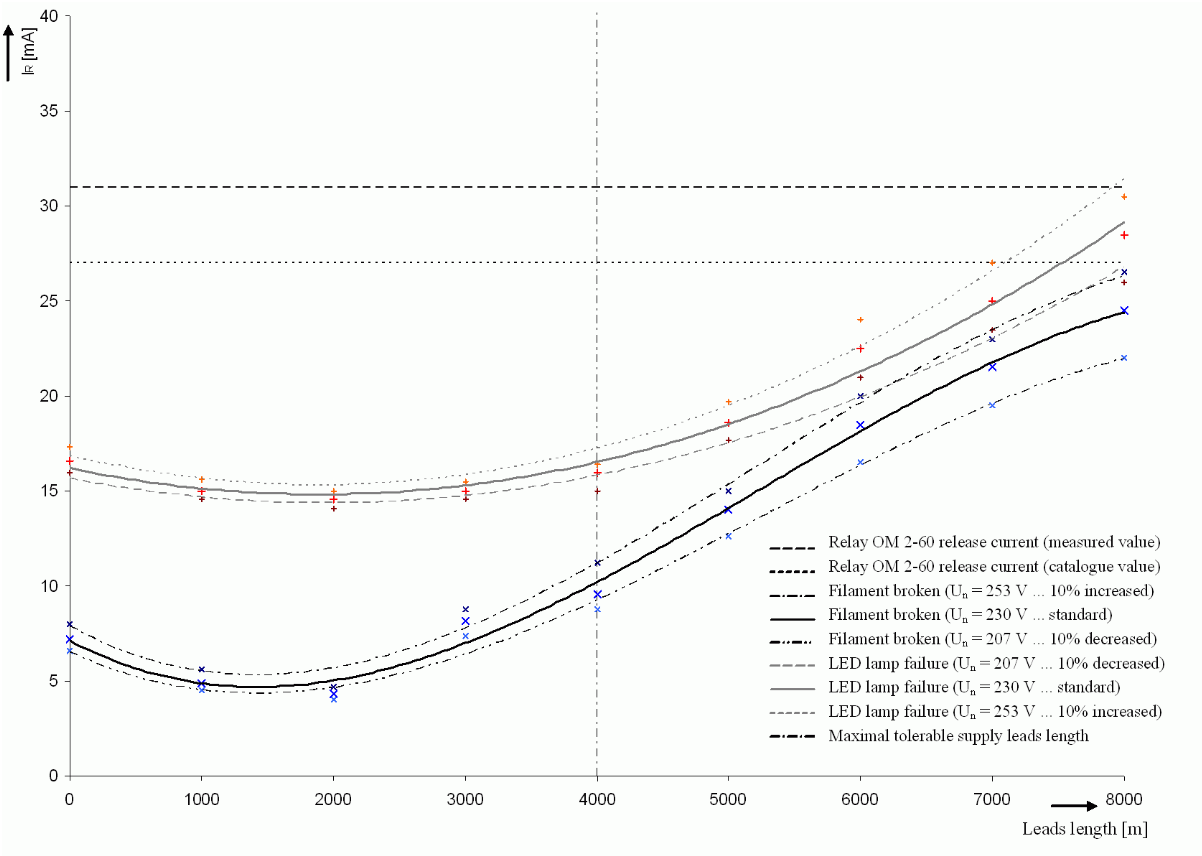


Fig. 5. Current in the circuit vs. the leads length
Source: [own work]

release current value. In the circuit measured the limit length of the supply cable is 7 kilometres.

The figure shows, that if the length of supply cable is set by standard [3], the light signal supervisory relay reliably releases in the worse operational circumstances.

6. Conclusions

The modernisation of interlocking gains importance not only in national but in international conditions, too. The decision on partial or full modernisation of interlocking systems is mainly conditioned by economic standing of railways.

The preservation of original safety integrity level is an important aspect in the case of partial modernisation of interlocking system.

The article deals with properties of modern LED lamps construction dedicated for replacement of older signal lamps with bulbs. The construction of these lamps could improve first of all optical properties and extend the service life. The construction must not make the safety of signal circuit worse.

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