Designing Automatic Railway Switch Heating System with Innovative Intelligent Sensors

Viktor Barausov[a], Vladimir Bubnov[b] and Shokhrukh Sultonov[b]

[a] *KTN LLC, Saint Petersburg, 196006, Russia*
[b] *Emperor Alexander I St. Petersburg State Transport University, 9 Moskovsky pr., Saint Petersburg, 190031, Russia*

Abstract
The paper offers analysis of ice/snow buildup sensors, meteorological and weather stations supplied as integral part of railway switches cleaning systems developed and produced by Russia-based companies and installed on railway switches of Joint Stock Company Russian Railways, with types and principles of operation of devices used also discussed. A block diagram of the formation of control actions of the icing or snow detection system on the controlled surface is carried out. The common types of icing sensors are considered separately, giving information about the conditions of icing, the formation of ice on the controlled surface. A rational method of the system for detecting icing or snow on the controlled surface of switches is proposed and justified. Based on the results of the work done, conclusions are drawn and recommendations are given regarding the creation of promising sensors of the indirect principle of action.

Keywords
SCRS design, electric heating systems, installation diagram, sensor elements, hardware, temperature sensors, ice/snow, pilot model.

1. Introduction

[1] Currently, effective solutions for prevention and elimination of snow and ice buildup on railway switches – a condition required for safe and uninterrupted railway traffic – used extensively by JSC Russian Railways (JSC RZD) rely primarily on systems with automatic snow and ice buildup removal [1].

Systems for cleaning railway switches (SCRS) are applied to remove snow and icing in the zones of switch points, frogs and guard rails as a necessary provision for uninterrupted railway traffic under the severe weather conditions of snowfalls, snowstorms and the like, typically followed by ice buildup on moving parts of railway switches thus preventing their normal operation [2-4].

The principle of operation of all electric heating systems is similar – electric current is supplied to a heating element mounted on the rail [5]. The basic SCRS design and the system components are shown in Fig.1.

Prevention of accidents and compliance with train schedule during winter season is attained with application of an effective method for cleaning moving parts of railway switches – the use of heat, specifically, electric heating. Such systems typically have tubular electric heaters (TEHs).

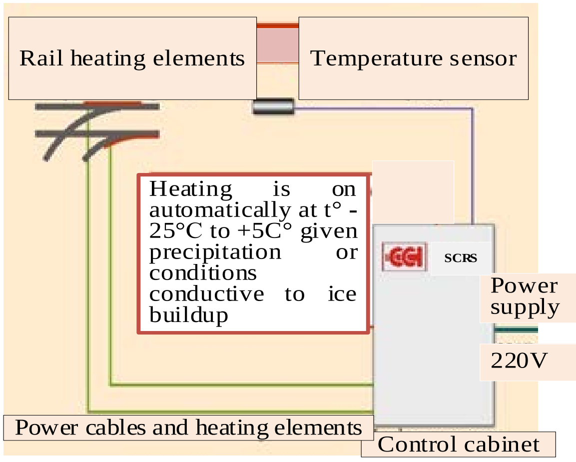

Figure 1: SCRS design and components

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EMAIL: info@idm-ktn.ru (V.A. Barausov); bubnov1950@yandex.ru (V.P. Bubnov); sultonovsh@yandex.ru (Sh.Kh. Sultonov).
ORCID: 0000-0002-8106-1192 (V.A. Barausov); 0000-0002-6742-3011 (V.P. Bubnov); 0000-0002-0462-8677 (Sh.Kh. Sultonov)

These are steel seamless tubes with Nichrome helix coil inside them and magnesium oxide used as insulator and placed between the coil and the tube [6].

Extensive application of electric heating as a method of cleaning railway switches was introduced in 1980s. First development was a system of electric heating solutions for railway switches based on railway switch heating cabinets (RSHC). The evolution of railway switches electric heating systems is shown in Fig.2.

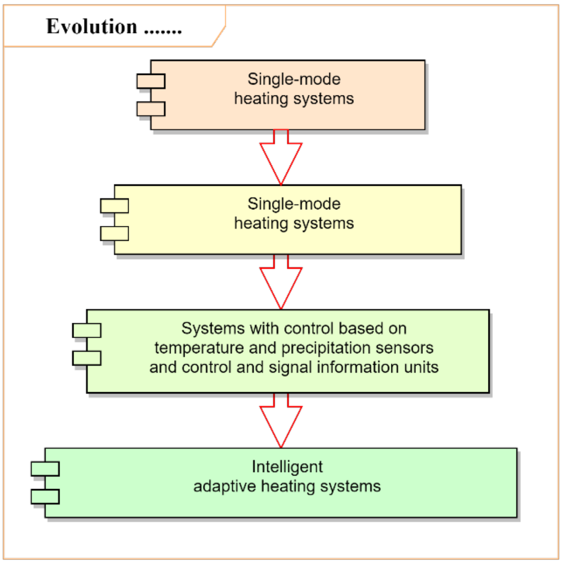

Figure 2: Evolution of railway switches electric heating systems

Modern higher standards of operational safety in the area of railway transportation have revealed a number of deficiencies in the systems currently in use: insufficient levels of switch rails surface cleaning; substandard levels of system operational power consumption efficiency; absence of flexible control arrangements, integrated diagnostics and monitoring functions in heating systems used.

Effective and efficient solutions to provide for compliance with the current operational standards of railway switches heating systems are to be based on integration of data collection and control functions into system, i.e. it is to be able to perform the functions of control, regulation, ice build-up prevention, and to determine the current level of railway switch operational safety, predict the nearest developments, generate the control input signal for heating system hardware and regulating components to parry and prevent any disruption in the system operation.

Automatic heating control in RSHC is performed with industrial controllers and requires collection of the relevant data generated by rail temperature sensors, air temperature sensors and humidity level and precipitation sensors (components of meteorological station equipment) [7].

Automatic operation of the systems discussed is designed to rely on ice and snow buildup detection sensors (also part of weather or meteorological station equipment). High reliability and precision of the sensor determines the overall heating system operation efficiency in both terms of energy savings and in terms of increased loads on power circuits and the system components in total [8].

Currently, two types of ice and snow buildup sensors are used by manufacturers of automatic SCRSs found in the Russian market and installed on railway switches by the JSC RZD. The following discussion is centered on comparative analysis of their principles of operation, advantages and disadvantages of both are also indicated [9].

2. SCRS design

Basically, within any SCRS 4 principal components can be identified – they all are individual elements and can operate independently to solve the tasks set, no interaction with other components and devices required (Fig.3) [10,11].

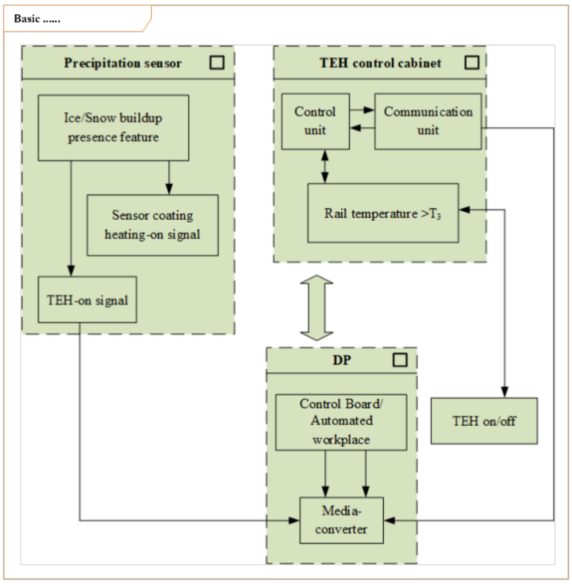

Figure 3: Basic SCRS block-chart

The first component is the electric heating equipment which performs the immediate function of supplying power to heating elements (indicated by switch heaters manufacturers as a model of control cabinet, e.g. SHOIT, SOSP, SOSP-M models marketed in Russia).

Typically, the design of heating equipment includes converters, power cables, electric circuits with various properties, control unit, circuit breakers, fuses etc.

The second component is software which provides for the data transfer or information exchange between the equipment and administrative unit, e.g. railway station operator or dispatcher, whose responsibilities include railway switch cleaning. The amount and accuracy of the data obtained depend on the tasks set by the customer to be solved by the system manufacturer. The data can include information on the amount of electric energy consumed, equipment operation parameters, errors, faults and malfunction in equipment operation. In addition, software may also regulate and change the mode of operation, initiate diagnostics procedures, and, if required, re-start the system after error detection or system failure.

The third component is the ice/snow buildup sensor which can be regarded a principal element of SCRS automation. Literally, it is the heart of the railway switch heating system – since operation of any such automatic system is impossible without a device detecting ice/snow presence.

The forth component is the SCRS hardware which provides for the condition of rail heating. It can include terminal boxes, heating elements (TEHs), shields, brackets for mounting TEHs.

3. Types of precipitation sensors and principles of their operation

Currently, the railway switches operated by JSC RZD are installed with two types of ice/snow buildup sensors – these are electro-thermal and optical sensors, which are described and discussed below.

Electro-thermal ice/snow buildup sensor is based on the principle of electro-thermal resistance: when precipitation (snow, in this case) appears on the sensor surface heated by a heating element it melts and the resulting liquid (moist) is drained through a special hygroscopic membrane into areas between electrodes and this process closes the electric circuit inducing lower values of electrode resistance – this condition causes a specific signal generated and transmitted to act as a control input.

This method was developed and patented in 1990 and today is extensively used in manufacture by leading Russian SCRS producers, LLC Ladoga-Energo in the North-West region (marketing SOSP-M model) and LLC KTN in the Rostov region (marketing SEIT-04m model). Based on its physical properties this type of ice/snow buildup sensor is defined as direct signaling device.

Direct signaling devices respond to an input in the form of ice buildup on the sensor detecting surface. The signaling sensitivity, with the sensors of this type, is largely determined by, first, the particular sensor dimensions and configuration, second, by its location on the rail it is to maintain and heat (Fig.4). The rate of sensitivity of the sensor is the higher, the smaller is its diameter (in case of cylindrical sensor), or the sharper its front part (in case of rectangular sensor) [12].

Figure 4: Principle of operation and installation diagram for electro-thermal ice/snow buildup sensor

The main disadvantages of this type of sensor are the following:

1. Comparatively short life: continuous operation in high-humidity conditions reduces the useful life of this type of sensor to an average of 60 days, thus requiring regular replacements and creating operation issues.
2. Excessive number of false positives: even the presence of a number of additional sensors (air temperature sensor, rail temperature sensor, ground temperature sensor) reduces the number of false positives by the sensor discussed only insufficiently which prevents correct decision-making and optimized operation.

3. Inability of the sensor discussed to detect the presence of ice/snow buildup on controlled surface in case of snow drifted by wind or any other external impact, e.g. a passing train.

4. In fact, this type of moisture-detecting sensor in its operation and detection of ice/snow buildup presence on the controlled rail requires a number of additional external parameters.

To solve this problem, manufacturers of such sensors try to improve their reliability by adding computational data to detection process; however, the solution appears ineffective judging the statistics of SCRSs regular repairs and maintenance and replacement procedures disclosed by railway authorities [13].

Optical ice/snow buildup sensor has a number of advantages as compared with the above discussed sensor, despite the fact of being characterized as an indirect signaling device.

Indirect signaling devices respond to presence of water drops in the environment sensed. The principle of their operation is based on measurement of indirect factors related to ice/snow buildup process: heat transfer rate, electrical conductivity and resistance values.

Signaling devices of this type are characterized by high sensitivity rates: the signal of buildup detection is generated either simultaneously with ice/snow buildup process, or, sometimes, several seconds before the process is initiated, due to increased humidity rates and changes in temperature in proximity to cloud.

The principle of sensor operation is based on changes in parameters of direct and reflected sunrays given the condition of precipitation (rain or snow) present in the air (Fig.5). Using the data from the multi-channel infrared sensor sensing direct and diffuse rays reflected form precipitation and a number of supplementary sensors, the sensor discussed generates a signal of precipitation and possibility of ice/snow buildup.

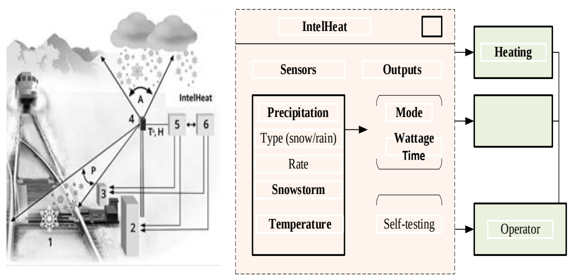

Figure 5: Principle of optical ice/snow buildup sensor operation

In addition, such principle of operation allows for detecting the presence of ice buildup on controlled surface given the sensor itself is mounted in immediate vicinity to the railway switch. The principle of operation described and the sensor based on it are used in SCRSs manufactured by LLC KTN Saint Petersburg and protected by patent [5].

In brief, the principle features of intelligent ice/snow buildup sensor manufactured by a by LLC KTN Saint Petersburg and integrated in its ice buildup preventing SCRS model are: mono-block (single-piece) design; small dimensions and weight; optical method of ice/snow buildup detection underlying sensor principle of operation; function of self-testing; digital interface. The system is supplied with an additional sensor to improve the measurement accuracy and system efficiency.

The above analysis allows for the following conclusions to be made:

1. Variety in names used to indicate ice/snow buildup sensor, i.e. Weather Station, Meteorological Station etc, confuse current and prospective customers of SCRSs in terms of functionality, purpose and features of the devices and systems purchased.

The principal purpose of ice/snow buildup sensor is to detect the presence of snow or ice cover on the controlled (heated) surface irrespective of the weather conditions present (snowstorm, thaw, rain freezing into snow and snow melting into rain, snowdrifts caused by wind or passing trains etc.). Hence, its main purpose and its logical application is exclusively that of a signaling device to detect two conditions – presence or absence of precipitation.

A task to be solved as a prerequisite to further developments is unification of terms used to denote various types of equipment used for this purpose by JSC RZD.

2. Sensors for ice/snow buildup detection currently used by JSC RZD have different principles of operation, which can be regarded a condition favorable for increasing competition among SCRS manufacturers.

This condition, however, is not to imply a compromise in terms of sensor efficiency and reliability. Currently, even warranty maintenance can seldom guarantee secure and reliable operation of the equipment discussed, and manufacturers, in case of malfunction or failure, are unable to either immediately, or in the shortest time possible, solve the problem arising.

At best, the equipment is switched to manual control mode, thus requiring constant involvement of human operator, and in such case the equipment cannot be claimed to meet the requirements in terms of both parameters and quality of its operation. If this condition develops, it is often inductive to both direct and indirect financial losses by railway operator.

The analysis performed provided a foundation for further research and development in the field that allowed for elaboration of both the method and the design for a device to detect ice/snow buildup having none of the deficiencies described above.

4. Method and design for ice/snow buildup detection device

The development proposed is to produce a universal sensor which will find application in various industrial scenes. The sensor operation is based on a new physical method, different from those already present in the market [14-16].

The method underlying the device operation and technical solution for the ice/snow buildup detecting device are shown in Fig.6.

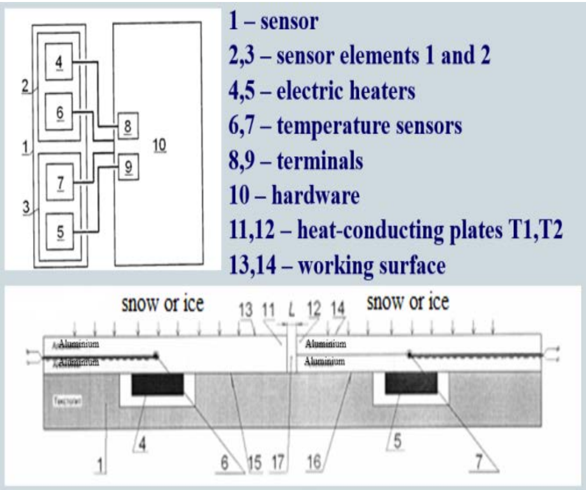

Figure 6: Method and technical solution for ice/snow buildup detection on controlled surface

The device integrates a sensor with identical and isolated from each other sensor elements and programmable hardware with units for control, measurement, data processing, indication, signal registering and data transfer.

Calculation and computation required for the device development can be divided into two principal areas [17-20]:

- Interpretation of physical processes into program code;
- Control of hardware and software.

Sensor design provides for properties allowing the device to resist mechanical impact, any environmental conditions, making it suitable for reliable operation in hazardous environment – under such conditions the device can be placed immediately in the controlled area. This solution is classified as direct signaling device. If the device signals precipitation presence detected it means ice or snow are positively present on the controlled surface.

Sensor design can be changed and adjusted to meet a wide range of specific purposes and sensor location requirements in relation to various control objects. Fig.7 shows the pilot model and ice/snow buildup sensor installation on testing ground.

Figure 7: Ice/snow buildup sensor pilot model and its installation on testing ground.

5. Conclusion

The principal element of railway switch automatic heating system is the integrated signaling device (ice/snow buildup sensor). It gradually replaces previously supplied RSHCs and provides for increased reliability, efficiency and useful life of railway switches heating elements and systems while allowing for most advanced techniques and solutions in control and diagnostics to be integrated in system designs.

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