Simulation modeling in methods and designs for detecting ice or snow buildup on control surface in MATLAB/SIMULINK dynamic modeling environment

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Abstract
Programming languages and hardware are reviewed in terms of their application for purposes of simulation modeling. The algorithm for electric heating system design is offered. Development and testing procedures for electric heating system solutions use MATLAB/SIMULINK dynamic environment.

Keywords
Automatic system for cleaning turnouts, a sensor for detecting ice or snow, a block diagram of a control action, a method for detecting icing or snow on a controlled surface, a control program algorithm, a simulation model.

1. Introduction

In the process of implementing supply chain management (SCM) in practice, managers have faced with the problem of adapting to customers' unplanned orders and individual technological and economic requirements. How and with what methods and technologies is it possible to assess the reliability and stability of the supply chain in the event of Maintenance of railway switches in snow and ice buildup-conductive weather conditions is labor- and time-consuming operation incurring substantial maintenance costs.

Switch operation maintenance during winter season requires either substantial regular physical effort, or high energy-consumption in all currently used mechanized cleaning techniques, it also results in additional strict requirements to accident prevention measures and arrangements and many more.

Innovative and improved methods and designs for mechanized snow and icing removal in maintenance of railway switches operating conditions during winter season have always been and still are regarded a primary necessity in railway industry with effective and efficient solutions to be developed.

Currently railways operate multiple methods for removing snow and ice buildup on railway switches – at least in their moving parts – depending on specific weather conditions. Often optimal solution is the one combining maximum compliance with the requirements for railway switches operation standards and low maintenance costs under existing requirements in the fields of industrial safety and environmental protection.

To prevent cold-weather-conditioned failures of remotely-controlled railway switches and other mechanical devices railways today make extensive use of various designs and devices as local heating arrangements. Classification of heating and snow and icing-removal methods is shown in Fig.1.

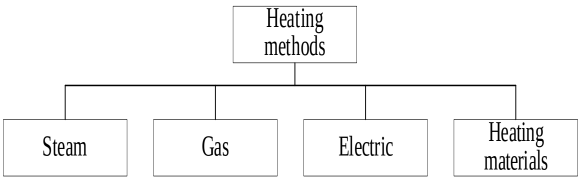

Figure 1: Classification of heating and snow and icing-removal methods for railway switches

Prevention of ice-formation and provisions for standard operation of moving parts in the railway switch require application of various means and methods for heating switch parts with those using electric heating most widely applied since these are most universal, relatively

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inexpensive and unsophisticated in operation and maintenance [1-4].

Analysis of control systems for railway switches electric heating with simulation modeling procedures allows for development and testing of highly complex systems. In such case simulation procedure goes beyond the procedure of functional model design. A further important stage is, having performed analysis of system designs for railway switch heating, to determine possible improvements in order to increase the heating system performance [4, 5].

Currently for removal of snow and ice build up on railway switches through heating Russian railways typically use SEIT-04M system which is made of the following components: several TEHs mounted on frame rails, outside air temperature sensor, switch, precipitation detecting sensor, comparing element with the outside air temperature sensor connected to the comparing element input slot, the system has a single rail temperature sensor mounted on frame rail and connected to the comparing element input port [3, 5].

Development of automated control systems for switching between heating systems operation modes requires more advanced and efficient methods and designs for railway switches heating applications. The systems currently employed are considered to possess a number of drawbacks:

- no account is made of the heating system dynamic parameters in control and disturbance channels. Since the system controlled is characterized by a sufficient degree of inertia the system adjustment to changes in weather conditions is delayed;
- no information is offered by the system supplier as to the type (in connection to ‘input signal comparison’) of the electronic data processing (EDP) device; the terms ‘specific algorithm’ and ‘specialized software’ are given no explanation and description. Under such circumstances, the EDP device design can be suggested to be similar to an automatic controller of poorer quality and fewer options as compared to modern EDP devices – logic-based EDPs performing logic operations/functions with input data following the principles of algebra of logic and generating output signals relevant for the actual function values.

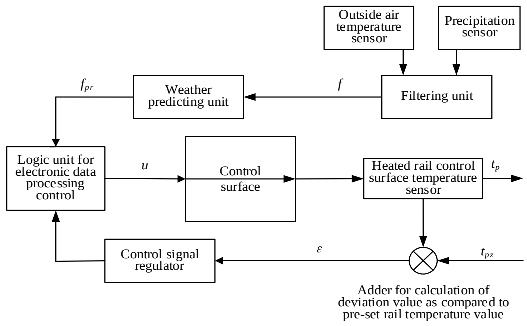
Solutions to these problems and development of effective system of control for adjustment of the amount of heat supplied to the element heated electrically require application of simulation modeling for [4]:

– solutions in methods and technical designs for detection of snow or ice buildup on control surface based on energy-efficient technologies for maintenance of railway switches operation;

– testing of the algorithms obtained for data-collection and control system designed for prevention of failures and emergency operation mode in railway switches.

2. Block diagram of control surface snow and icing detection system control signal functions

To provide for technical solutions in terms of compliance with the above-mentioned requirements the design shown in Fig.2 can be used given it was obtained by analysis of railway switch heating system operation as a control object [4, 5].



Where f – digitized disturbing effect data; f_{pr} – predicted disturbance, u – control signal (decision rule), t_{pz} – pre-set heated rail temperature value, ε – deviation value between effective and pre-set heated rail temperature values (divergence).

Figure 2: Block diagram of control surface snow and icing detection system control signal generation

Outside air temperature and precipitation values measured by sensors 1 and 2 pass filtering unit 3 for weather conditions prediction, the lower value is transferred to weather prediction unit 4 where the predicted outside temperature value within the weather prediction period is calculated generating precipitation possibility rate. Operation of the given open loop serves to detect icing probability using minimum outside air temperature value predicted.

Closed loop operation can be described in the following manner: Signal from sensor 5 measuring heated rail control surface temperature value is transferred to adder 6 where the heated rail control surface temperature value is compared to the pre-set value. The deviation value is transferred to control signal unit 7 and further to electronic data processing (EDP) unit 8 to adjust the value of output control signal of temperature prediction unit 4 for the heated rail. This arrangement allows maintaining the required temperature in heated frame rails depending on the outside air temperature and humidity parameters.

3. Design and procedure for snow and icing detection on control surface

Effective operation of a system designed for preventive adjustment of electric heating parameters require identification of designs and procedures for detecting snow or ice buildup on control surface.

The control surface is connected to sensors with two sensor elements carrying heat-conducting plates with outer working surfaces to detect outside air conditions, in-built plates temperature sensors and heating elements for plates inner surfaces (TEHs) [1-3, 6].

The method of snow or ice buildup detection offered requires identification and elaboration of algorithm structure, following this stage a simulation model for data collection and control program for a system to detect snow or ice buildup on railway switches is to be developed to test and improve the efficiency of control instructions generated.

In its operation the control program is to ensure the following functions:

- measuring the surface temperature value;
- measuring the outside air temperature value;
- input and processing of technological parameters-related data;
- reading pre-set values from secure digital (SD) memory card;
- storing the data inputs in SD memory card archive during a specified period;
- evaluation of the current condition as a reference to safe operation standards and, if required, generation of control signals for activation of heating elements to prevent deviation in parameter values within the railway switch electric heating system beyond the pre-set range;
- informing maintenance personnel of the emergencies detected, added by instructions and tips offered to automated workplace operator;
- visualization of the technological process parameters, of the recorded and archived data in easy-to-understand manner;
- program flexibility allowing for adjustment of operation algorithms in case it is required by the emergency condition parameters updates based on observed operation conditions.

The algorithm development is based on the architecture in the below block diagram offered for generation and adjustment of control signals in the system of ice or snow buildup detection on control surface (Fig.3) [7, 8].

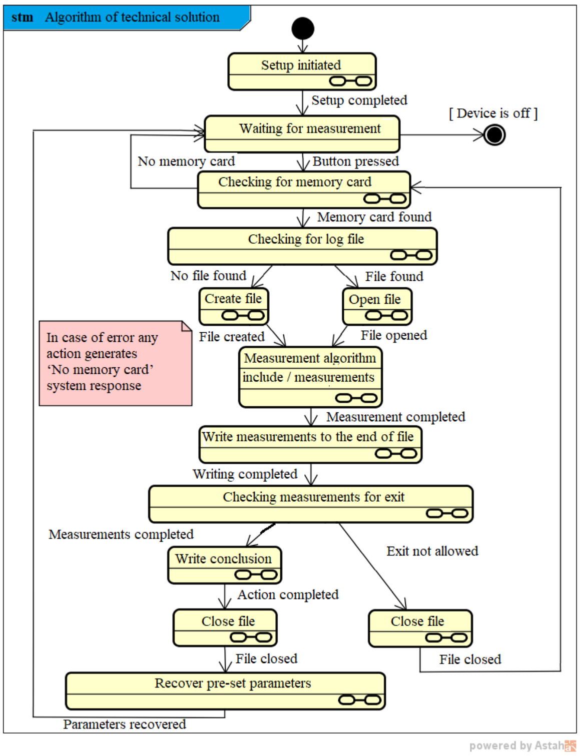


Figure 3: Algorithm for development of technical solutions for snow or icing detection on control surface

The device operation starts with initializing the micro-controller, input/output ports, setup of interruption handler. Further the system checks for SD memory card to ensure location for reading the stored data to measure temperature values on control surface in the heating system. Further the system waits for initialization of measurement procedure which is conditioned on the system signal generated. This signal can then be sent to other units or devices by, for instance, pressing the button. In checking for memory card procedure the system tries to access files on the SD memory card via API for Micro SD. The response is used to check for the file into which the measurements are written. In case no file is found, it is created. This procedure is followed by system activating power supply to sensors and reading the measurements during the interval set by the user. The algorithm of measuring values for preventive adjustment is shown in Fig.4 [6-8].

A more detailed description of the algorithm is provided further, since this algorithm is fundamental to the procedure offered in the present paper for precipitation icing detection which is used to maintain the control surface temperature parameters within the range set [7].

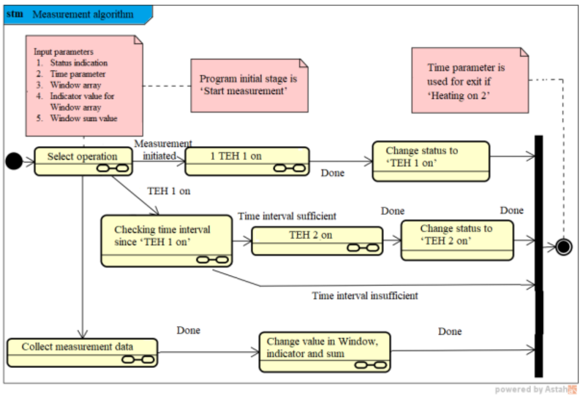


Figure 4: Algorithm of measurements for preventive adjustment and regulation of railway switch control surface electric heating system

The actual values of outside air temperature and precipitation measured by sensors are filtered in the weather condition prediction filtering unit in the immediate proximity of the control surface, the lowest temperature value obtained is then transferred to weather condition predicting unit where calculation of predicted outside air temperature values during the pre-set time interval is performed generating precipitation possibility rate.

The measuring procedure is performed in the following manner: signals from the control surface temperature sensors on the heated rail are transferred to respective adders; there they are compared to the pre-set temperature parameters for the heated rail given. Deviation values are transferred to regulators inputs and further to comparison-performing EDP unit, and adjustment of control signal parameters at the weather conditions predicting unit for the heated rail given is done. Such arrangement allows for maintaining optimum temperature for heating the frame rails conditioned on the outside air temperature and humidity parameters.

The architecture of the data collection and control system is designed in the manner allowing for a time lag Δt before activation of the second sensor heating element after activation of the first sensor heating element [6-8].

The algorithm offered is a combination of instructions and control algorithms for preventing possible emergency conditions reduced to the form which makes them applicable for designing and development of precipitation detection software solutions.

4. Development of simulation model for methods and procedures of snow or icing detection on control surface systems

Evaluation of systems to maintain required temperature parameters of the railway switch control surface in terms of their efficiency and performance can be done without a necessity to use expensive and sophisticated equipment. Currently, for the purposes of testing and experimenting applied research relies extensively on computer simulation modeling. A powerful tool for testing and analysis of simulated preventive adjustment control systems in their application for railway switch electric heating systems is SIMULINK, a general-purpose simulation environment. Simulation, in case of the applications discussed, allows models developed in this environment to be tested and verified for their performance, in terms of traditional simulation modeling. Partial presentation of results obtained in simulation to test system operation – detection of precipitation generating icing conditions on control surface – has been made in [8-10], simulation was also performed with MATLAB-based SIMULINK package.

Evaluation of the algorithm for measuring snow and ice buildup presence on control surface required development and testing of a computer simulation model in MATLAB environment which allows analysis of thermal processes dynamics in 'heated object' system.

Simulation models are often built with SIMULINK visual modeling tool, an extension of MATLAB package, designed for simulation of dynamic processes and systems in order to examine their operation and performance using graphic blocks [9].

Simulation model is characterized by features of continuous and discrete processes – this condition allows its application for studies of dynamic systems when the model sore points are tested and analyzed for functional dynamics. Another essential feature is that such model can be used in models requiring analysis of process dynamics during certain intervals.

Simulation process includes examination of method and device tested for effectiveness in detecting snow or ice buildup on control surface in condition of heating element activation.

Understanding of the operational design of electric heating system simulation model tested requires detailed description of its algorithm.

Analysis of electric heating control system with simulation modeling provides an opportunity to test and improve even highly complex systems. In such case the study of maintenance control system is seldom limited to simply modeling processes in it. An extremely important feature of such simulation modeling is the opportunity to introduce improvements and test their effects.

Calculation and identification of principal dynamic parameters of the electric heating process is performed using simulation model developed in MATLAB package extended with SIMULINK dynamic simulation module [10]. Simulation model discussed is based on the architecture shown in block diagram in Fig.2. The generalized block diagram of the electric heating control system model architecture is shown in Fig.5.

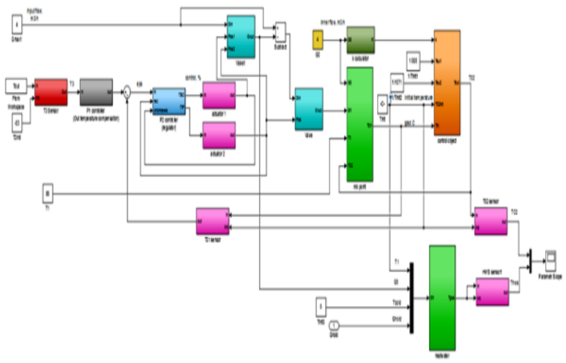


Figure 5: Block diagram of simulation model for system of precipitation detection on control surface

The diagram for electric heating system simulation model designed for heating rail as control object is shown in Fig.6 as ‘control object’ block, and given equation (1,2) can be presented as:

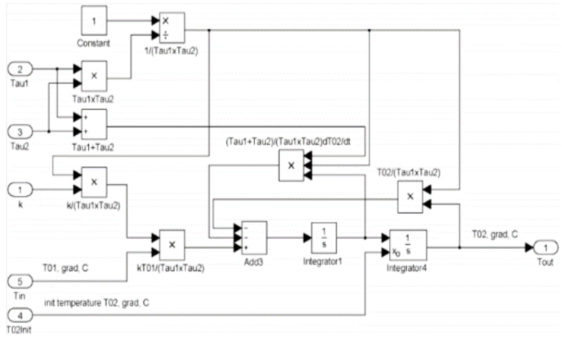


Figure 6: Block diagram of control object simulation model

Based on empirical experimental data, graph visualizing operation of precipitation detection method model given precipitation present is shown in Fig.7.

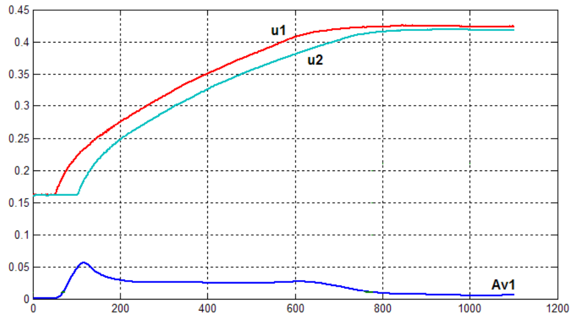


Figure 7: Graphs of sensor elements temperature values for sensors 1 and 2 and deviation values given time interval of TEH activation with TEHS activated asynchronically (experimental, given ice buildup present on sensor working surfaces), where temperatures T_1 and T_2 measured by thermo-sensors are shown as u_1 and u_2 respectively, deviation values u_1' and u_2' are shown as *Av*1

The graph visualizing operation of precipitation detection method model given precipitation absent is shown in Fig.8.

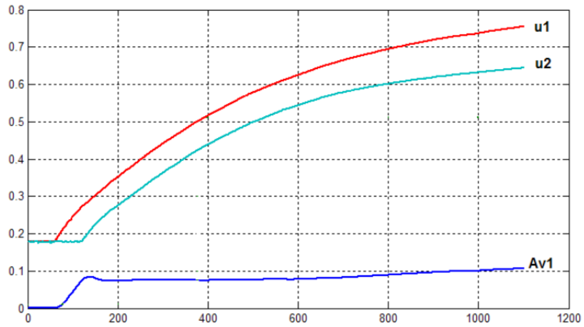


Figure 7 and Figure 8 show time intervals in discrete units along the x-axis, and temperature in measurement units (convertible in any standard units, e.g. Celsius degrees, given these units were obtained empirically) along the y-axis. To improve clarity of presentation the curves for u_1 and u_2 heating process values are shifted down by temperature value.

5. Conclusions

Given such conditions the control system provides adjusting response to both deviations from ideal mode already detected and conditions in which the tendency for further deviation has been just identified. To compensate for residual standard errors and to provide for stability of the control system being synthesized the object is closed with feedback of the actual output value compared to the pre-set value. This signal is transferred to regulator unit input which, given any deviation value, adjusts control signals generated.

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