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CALCULATION OF THE TEMPERATURE DISTRIBUTION IN HEATED SWITCH POINTS

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Abstract

Snow and ice can accumulate between the moveable parts of a switch point during the winter season. As a result he point cannot be switched anymore. In order to prevent failures and delays of trains, switch points are heated. Electrical heating rods shall ensure the melting of snow and ice in the critical areas of a point. Practical experiences have shown that this is not always possible. A calculation model for the heating of a point has to be set up in order to investigate the effectivity of switch point heating systems. Besides that, various ambient factors (such as ambient temperature, wind, precipitation) reduce the heating of the point. However, the extent of impact of the weather conditions on the heating remains to be investigated. Therefore, it is important to study their thermal influence and implement it into the calculation model. The Thermal Network Method (TNM) is suitable in this case. Initially the single main components of a switch point will be set up in separate networks. After a verification with experimental setups, the separate networks can be connected to each other. An experimental setup of an entire model point gives the opportunity to compare calculated and measured heating results without the influence of weather conditions. Finally, the ambient conditions can be implemented into the TNM model by performing field tests. The finished model can give high-resolution temperature information for different heating powers, ambient temperatures, wind velocities, rain and snowfall. According to the practical experience of various railway companies the temperature distribution is calculated for different parameter scenarios and subsequently evaluated regarding its effectivity to prevent failures.

Keywords: switch point, snow and ice, electrical heating, failures

1 Introduction

In the winter months a malfunction of points (railroad switches/turnouts) can occur, due to an accumulation of snow and ice at the moveable components of a point. Thereby, the setting process of a point is prevented and the point cannot be passed by trains anymore. In order to avoid train cancellations and delays, point heating systems are utilised. They have the aim to melt the impeding snow and ice and, therefore, ensure a safe and faultless setting of a point. Electrical heating rods are one possibility to generate thermal energy and feed it into the point. Railway companies have been using them for many years. However, points could not be kept free of snow and ice under certain weather conditions. So, there is a demand for a closer analysis of the heat transfer and the temperature distribution in a point. The different components of a point will be individually investigated thermally and eventually merged to one calculation model. The already existing findings on the temperature distribution in the stock rail [1] constitute the basis of these investigations.

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2 Theory of heat transfer

In order to calculate the heating of a point, three thermodynamic processes for heat transfer have to be mainly considered: heat conduction, convection and radiation. Within one body or at the interface of two touching bodies, heat conduction takes place. The heat transfer is always directed from the location with the respective higher temperature to the location with the lower temperature. The heat flow Pc transferred by conduction can be calculated with the specific thermal conductivity l by Fourier's law (Eq. (1)) [2].

$$P_c = -\lambda \cdot A \cdot \text{grad}\,\vartheta \tag{1}$$

If there is no direct contact between two bodies, thermal energy can be exchanged by heat radiation and convection. In the case of heat radiation, there is no need for a transfer medium. Electromagnetic waves transfer the heat between two surfaces of different temperatures (T1 and T2) according to the Stefan-Boltzmann-law (Eq. (2)).

$$\mathrm{P_r} = \varepsilon_{1,2} \cdot \sigma \cdot A_s \left(T_1^4 - T_2^4\right) \tag{2}$$

The resulting emissivity e1,2 of both bodies depends on the surface condition, whereas s is the Stefan-Boltzmann constant. The convective heat transfer describes the heat exchange between a solid body and a fluid. This process can be devided into the heat conduction from the solid to the fluid and the flow of the fluid. Depending on the kind of the movement, a laminar flow and a turbulent flow can be distinguished. Furthermore, the cause of the flow determines whether it is free or forced convection. There is only density differences that cause the flow for free convection while an external drive like pumps or fans cause a forced convection. The thermal power transmitted by convection can only be calculated accurately for simple geometric conditions. Similarity functions are used to cover all the other cases (Eq. (3)) [1].

$$\mathrm{P}_{CD} = Nu \cdot A_s \cdot \left(\vartheta_1 - \vartheta_0\right) \cdot \frac{\lambda}{l_w} \tag{3}$$

The values for the Nusselt-number Nu and the characteristic length lw originate from experimental investigations, whereas l describes the thermal conductivity of the fluid.
Analogies between electric and thermic networks are suitable in order to calculate the heating of a body. That means electric quantities and their relations to each other can be transferred onto thermic quantities (Table 1).

Table 1 Relation between electric and thermic quantities

Field type	Electric	Thermic
current / heat flow	I	P
potential	φ	ϑ
resistance	R_{el}	R_{th}
potential difference	$\Delta\varphi = U = I \cdot R_{el}$	$\Delta\vartheta = P \cdot R_{th}$
capacity	C_{el}	C_{th}

3 Setup of the Thermal Network Method (TNM) model

The TNM uses the analogies between the electric and the thermic field in order to calculate the heating of a model. Thereby, thermal nodes divide the model into sections. Thermal elements (e.g. resistors for radiation, convection and conduction, thermal capacitors and temperature or heat sources) connect those thermal nodes. The result of a TNM calculation is an assigned temperature to each thermal node and an assigned heat flow through the connection of two thermal nodes. The TNM is capable of calculating models with a high number of thermal nodes within a short computing period. This circumstance favors this method for extensive parameter studies. An additional advantage of the TNM is the possibility to connect and combine single separate networks. This overall approach was also used for setting up the TNM model of the point. An entire point consists of various components. Because the heating of these components was not known so far, they were initially investigated separately. The general procedure is listed below:

- setup of TNM models of single components of a point
- experimental verification of the separate TNM models
- connection of the separate TNM models to one model
- experimental verification of entire point model under laboratory conditions
- implementation of weather conditions and experimental verification in open field scenarios

The main components of a point are the stock rail, the tongue rail, base plate with the slide chair and the track bed (Figure 1). The heating rod is also an important part for electrically heated points and thus has to be modelled thermally. This paper only considers the utilization of one heating rod that is fixed at the foot of the stock rail. The detailed setup of the thermal model for the stock rail and the heating rod was already topic in the in the previous publication [1].

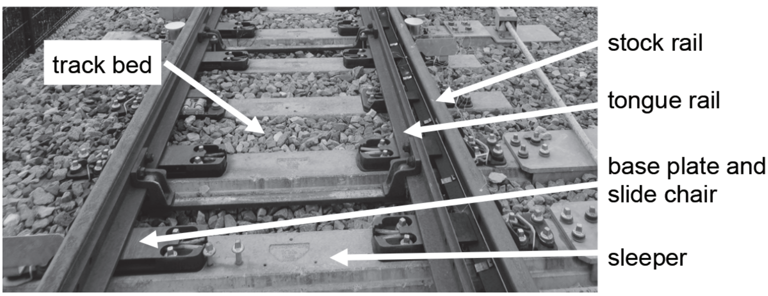


Figure 1 Main components of a point

The TNM models for the tongue rail, base plate, slide chair and the sleeper were set up analogously to the setup approach for the stock rail. Initially, the component geometry was approximated and divided by thermal nodes. While resistors for conduction connect the thermal nodes within the component, resistors for convection and radiation realize the heat transfer at the interface between the component and the ambience. Additionally, the implementation of thermal capacitors at respective nodes enables a time-dependent heating calculation. The thermal parameters of the elements were first estimated according to the literature [1] and adjusted if necessary based on the experimental measurement results subsequently.

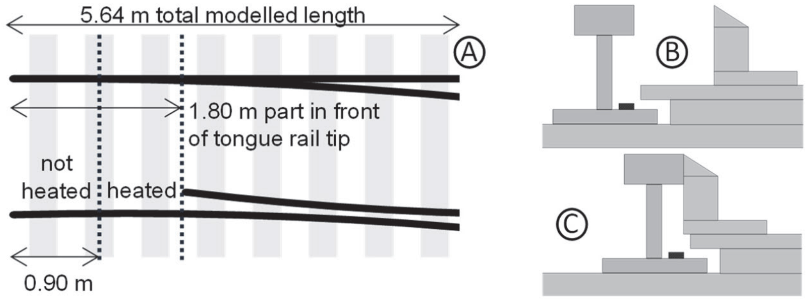
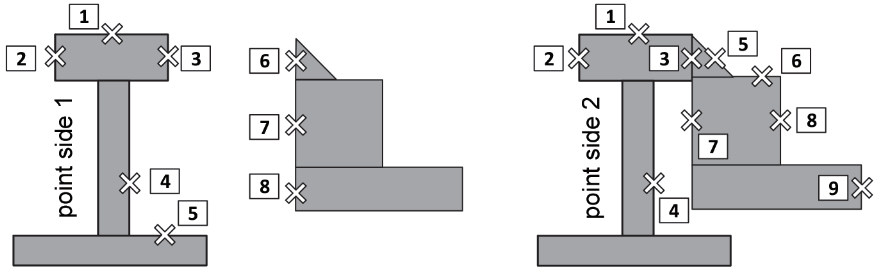


Figure 2 a) Longitudinal sections of the point in the TNM model; b) Point side 1 with detached bearing of stock and tongue rail; C) Point side 2 with touching stock and tongue rail

In contrast to the stock rail, the cross section and the circumference on the tongue rail change in longitudinal direction. In order to model the tongue rail, the TNM models of various sections were set up independently regarding their geometry and connected with each other afterwards. Experimental tests of the sleeper showed that there is no significant heat flow from one side of the point to the other via this component. The examined sleepers were made of concrete. Its low thermal conductivity of l = 0.2 W (mK)-1 [3] causes a thermal decoupling of the point side 2 where stock rail and tongue touch each other and point side 1 where they have a detached bearing from each other (Figure 2). Thus, two separate thermal networks, each for one side of the point, can model the heating of the entire point. This option reduces the number of thermal elements in each model and thereby the computing time. Another advantage of the low thermal conductivity of the sleeper material is the fact that the track bed has not to be modelled as a component. The heat flow from the sleeper into the track bed is rather low and does not affect a noticeable heating of the track bed. That is why, simple temperature sources with ambient temperature are sufficient to emulate the thermal effect of the track bed.
The both TNM models (one for every side) cover a total length of approx. 5.64 m of the point. That also contains an additional section of 1.80 m in front of the tongue rail tip. This section is important for calculating the longitudinal heat flow. The first half of this additional part is not heated. In the second half heating rods are mounted as in the remaining point (Figure 2).
A physical model point served for an experimental verification of the TNM model under laboratory conditions. Heating rods, mounted at the foot of the stock rail, with a power of P' = 300 W/m heated the point until the thermally static state. Thermocouples (type T) at eight or nine different positions respectively measured the temperatures. The comparison between calculated and measured temperatures shows only minor differences (Figure 3).
The measured temperatures confirm the accuracy of the chosen thermal parameters in the TNM model. In order to calculate the heating of a point depending on the weather conditions subsequently, affecting ambient factor have to be analysed and implemented into the thermal network.

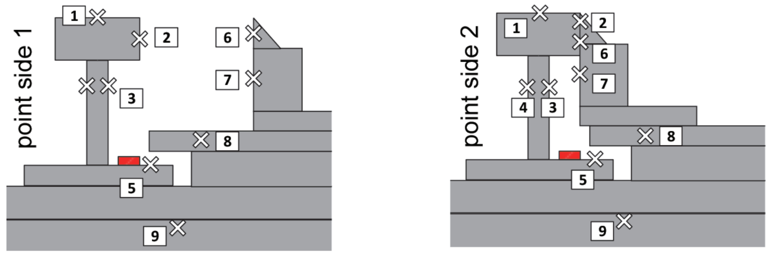


	pos.	1	2	3	4	5	6	7	8	9
point side 1	Q_{meas} in K	30.5	30.2	30.9	38.8	46.5	6.5	6.5	6.3	-
	Q_{calc} in K	32.4	32.3	32.4	37.4	45.0	8.4	8.2	8.7	-
	ΔQ in K	1.9	2.1	1.5	- 1.4	- 1.5	1.9	1.7	2.4	-
point side 2	Q_{meas} in K	34.0	33.2	30.0	44.9	21.5	20.7	22.4	20.7	19.3
	Q_{calc} in K	35.5	35.3	35.5	41.7	21.1	21.0	21.3	21.0	19.9
	ΔQ in K	- 1.5	- 2.1	- 5.5	3.2	0.4	- 0.3	1.1	- 0.3	- 0.6

Figure 3 Measured and calculated temperature rise (Q = J – Jamb) at a physical model point under laboratory conditions for a heating power of P' = 300 W/m and an ambient temperature Jamb = 24.0 °C for point side 1 and Jamb = 23.1 °C for point side 2

4 Implementation of weather conditions

The ambient temperature, wind, global radiation and precipitation can have a great influence on the heating of points in the first estimation. While adjusting the ambient temperature is a trivial process in the TNM model, the other factors need further research. The wind speed affects the convection process. In the presence of wind, the free convection changes to forced convection and the heat transfer coefficient rises significantly. Thereby, it is important to estimate the respective wind speed at the surfaces. On the one hand, the wind speed depends on the altitude and decreases by decreasing height because of increasing friction with the ground [4]. On the other hand, not all surfaces of rail components are affected by the wind to the same extent. Especially at the surfaces between tongue rail and stock rail there is only a reduced influence of the wind due to the cavity. Besides the wind speed, also the direction of wind affects the convectively emitted heating power. The heat transfer coefficient for convection is highest for a perpendicular angle between the longitudinal axis of the rails and the wind direction and reaches its lowest value for a parallel alignment [5].
Global radiation results from direct radiation and diffuse sky radiation reflected by the atmosphere. It represents an additional heat input at the point. Depending on the daytime, season and clouds various surfaces of the point components are affected to varying extents. Several thermal power sources feed the energy of global radiation into the TNM model of the point at respective surfaces.



	pos.	1	2	3	4	5	6	7	8	9
point side 1	Q_{meas} in K	17.9	17.1	19.1	21.9	27.3	3.8	3.8	11.9	0.3
	Q_{calc} in K	16.3	16.3	17.9	17.9	28.2	2.0	2.0	9.7	1.1
	ΔQ in K	1.6	0.8	1.2	4.0	-0.9	1.8	1.8	2.2	-0.8
point side 2	Q_{meas} in K	16.1	15.2	17.8	20.8	29.6	16.7	15.4	11.9	3.5
	Q_{calc} in K	15.4	14.6	19.0	19.0	31.8	14.6	13.1	12.8	1.2
	ΔQ in K	0.7	0.6	-1.2	1.8	-2.2	2.1	2.3	-0.9	2.3

Figure 4 Measured and calculated temperature rise (Q = J – Jamb) for a point under open air conditions

Precipitation can occur in forms of rain or snow. Its thermal effect on the heating of a body is highly complex because different thermal processes work at the same time. Heating experiments with a sprinkled model point were carried out under laboratory conditions. Their results could be used to implement rainfall and snowfall into the TNM model of the point.
All those modifications enabled the TNM model to calculate the heating of a point even by considering weather conditions. A comparison of measured and calculated temperatures validates the accuracy of the model (Figure 4).

5 Analysis of the heating effectivity

The functioning of the set up TNM model offers the possibility to evaluate various heating scenarios. The focus will be on point side 1, because it has the lower temperatures and is therefore the thermally more critical side.
Assuming the area on the inside of stock rail and tongue rail as well as on top of the slide chair should not give water or snow the opportunity to freeze or accumulate, the temperatures should not be less than 0 °C at those positions. Due to possible inaccuracies of the thermal network, the thermal requirement will be 2 °C at the mentioned locations for the following considerations. In order to meet this requirement one heating rod that is mounted on the foot of the stock rail must have a heating power depending on the ambient conditions (Table 2).

Table 2 Required heating power under different weather conditions to reach at least a temperature of 2 °C at the inner side of stock and tongue rail as well as on top of the slide chair

Ambient temperature	Wind	Precipitation	Heating power
0 °C	-	-	< 100 W m^{-1}
-5 °C	-	-	230 W m^{-1}
-10 °C	-	-	410 W m^{-1}
0 °C	15 km h^{-1}	-	540 W m^{-1}
-5 °C	15 km h^{-1}	-	2050 W m^{-1}
0 °C	-	strong rain (5 mm h^{-1})	> 3000 W m^{-1}
-5 °C	-	snowfall (2.5 cm h^{-1})	> 3000 W m^{-1}

This analysis shows that the influence of wind and precipitation increase the required heating power drastically. The chosen values for wind or precipitation have an amount, European railway companies absolutely take into consideration. Conventional heating rods have a nominal power up to approx. 450 W m-1. That means, a moderate wind speed of 15 km h-1 and an air temperature below 0 °C or precipitation at a temperature of 0 °C or below cause significant issues regarding the heating of a point. The analyzed heating system will not be capable to keep the point free from snow or ice. The coldest area was the inside of the tongue rail in all cases. It has the greatest distance from the heat input and so the least amount of heat reaches this area. The majority of heat will be emitted to the ambience before getting to the tongue rail (Figure 5).

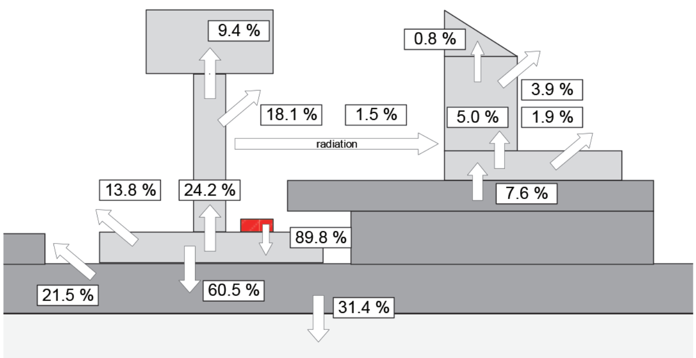


Figure 5 Proportional heat flows between point components (vertical/horizontal arrow) and to ambience (diagonal arrow) without influence of wind or precipitation

6 Conclusion

The verified TNM model of a point could show that for the using of a single heating rod at the stock rail an effective heating operation is only assured if snowfall/rain and wind do not occur at an ambient temperature of 0 °C or below. The point heating cannot prevent the area between stock rail and tongue rail from accumulating ice and snow in the presence of wind or snowfall and a malfunction of the point setting might happen.

In order to improve the heating, a consideration of a distributed heat input e.g. by using multiple heating rods should be carried out. It is difficult to reduce the heat emission to the ambience, so this method helps to transfer the thermal energy to the thermally important areas.

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