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TEMPERATURE DISTRIBUTION AT RAIL AND HEATING ROD RESULTING FROM VARYING THERMAL CONTACT RESISTANCES BETWEEN HEATING ROD AND RAIL OF HEATED SWITCH POINTS

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Abstract

Electrical switch point heatings consist of heating rods that are attached to the rail with clamps. Usually these clamps have a width of $w \leq 35$ mm and they are set in a distance of $d = 30$ cm to each other. The clamping force and the resulting thermal contact resistance in the area of the clamp was previously investigated [1]. Due to the large proportion of the heating rod that is not covered by a clamp and the uncertainty of the mechanical properties of the heating rod, a clear statement about the distribution of the mechanical stress at the contact area in longitudinal direction cannot be made. That means the thermal contact resistance can vary in a large range. In order to determine the impact of varying thermal contact resistances at the clamp area and at the area between the clamps, a Finite Elements Method (FEM) model of a rail and an attached heating rod was set up. Heating calculations with various thermal contact resistances show that the temperature distribution in the rail is mainly affected by the thermal contact in the clamp area. The heat transfer into the rail does not benefit from an increased clamping force or a special treatment of the rail surface like milling or usage of a thermal-conducting paste. Even a reduction of the clamping force over time due to mechanical or thermal load on the clamps does not decrease the temperatures significantly in the rail. However, the temperature distribution within the heating rod is strongly dependent on the thermal contact resistance in the area between the clamps. A large contact resistance between the clamps causes very high temperatures at the heating rod that accelerate ageing processes and can eventually lead to the malfunction of this part.

Keywords: switch point heating, turnout heating, heating calculation, thermal contact

1 Introduction

Switch points (or turnouts) play an important role in the railway infrastructure, since they enable the train to change its track without interrupting the travel. In order to achieve a change of the track, the tongue rail (moveable rail at the switch point) is set. During the wintertime, snow and ice can accumulate at the switch point and prevent it from setting. This malfunction can lead to delays and cancellations of train services. Switch point heatings are utilized to maintain the setting capability of a switch point. Electrical (resistive) switch point heatings are often a technical application of switch point heatings in European countries [2]. The specific thermal contact resistance is a quantity to evaluate the heat flow through a thermal contact. It should be as low as possible so that as much of the heat generated in the heating rod as possible reaches the stock rail. Previous investigations showed that the specific heat transfer resistance between the heating rod and the stock rail is affected by the surface treat-

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ment of the rail e.g. milling or usage of thermal-conducting paste and can be affected by the joint force [1]. A strong variation of the thermal contact resistance between heating rod and rail can be assumed in longitudinal direction, due to the installation of the heating rod with the heating rod clamps. This article shows an investigation, to what extent the temperature distribution in heating rod and rail depends on the respective thermal contact resistance. Based on these findings, a statement about a meaningful surface treatment of the rail and a required joint force will be made.

2 State of the art

2.1 Electrical switch point heating

Electrical heating rods provide the thermal energy for electrical switch point heatings. They consist of a forward and a return conductor generating heat by Joule heating. The conductors are electrically insulated and covered by a metal jacket. The metal jacket is usually made of a stainless steel. The geometric shape of the heating rod's cross sections is not standardized, but an oval cross section is one of the most common shapes (Figure 1). Clamps made of spring steel attach the heating rod to the stock rail. Various attachment positions at the stock rail are possible. Most of the times, the heating rod is attached to the foot of the stock rail. The heating rod clamps have a width of approx. 35 mm and they are installed in a center-to-center distance d = 0.30 m.

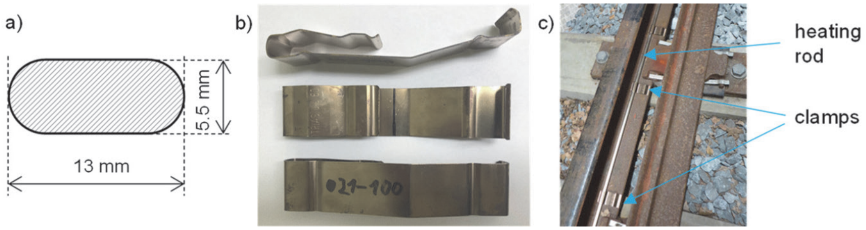


Figure 1 a) Common cross section of heating rod; b) Uninstalled heating rod clamp; c) Installed heating rod with clamps at the foot of the stock rail

2.2 Thermal contact of rail and heating rod

The surfaces of real bodies are rough [3]. Within the macroscopically visible contact area (apparent contact area), the contact members only touch at certain areas (Figure 2). These areas sum up to the load bearing area. A proportion of the load bearing area might be metallic contact spots for the contact between the metal jacket of the heating rod and the stock rail. However, it can be stated from experience that a corrosion layer covers the majority of the rail surface and so a rail surface covered with a corrosion layer constitutes the majority of the load bearing area. Cavities occur, where no load bearing area is located. Under open-air conditions, those cavities are mostly filled with air, but can also be filled water or other foreign matter.

A heat transfer by convection between the rail and the heating rod can be neglected due to the small size of the cavities (micrometer range). Considering the temperature differences of both contact members, heat conduction also dominates the radiative heat transfer [4]. The heat conduction can occur through the metallic contact, through the corrosion layer, and through the cavities.

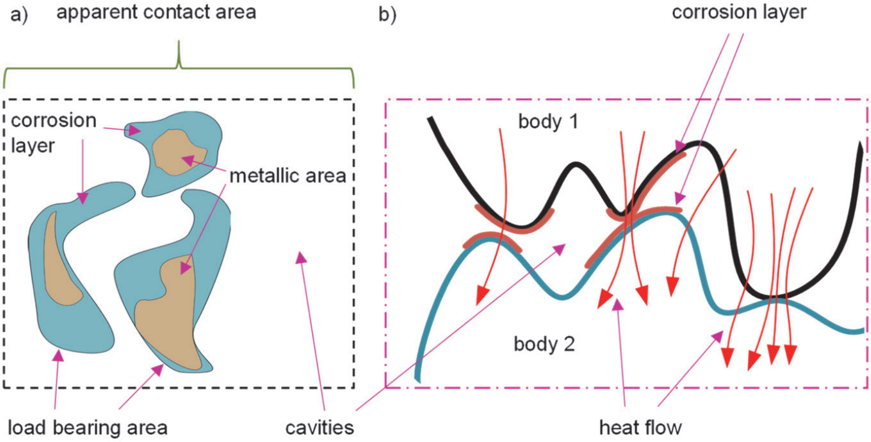


Figure 2 a) Definitions of the contact area from the top view; b) Heat flows through metallic contacts, corrosion layers, and cavities between rough surfaces of two contact members [1]

One of the most common railway steel grades is R 350 HT with the steel number 1.0631 [5]. It belongs to the low-alloyed steels. Different corrosion layers are formed on low-alloyed steels, depending on the environment conditions. The corrosion products have a porous structure and their growth does not stop over time [6]. The thermal conductivity of the corrosion layer plays a crucial role for the thermal contact between the rail and the heating rod, since the majority of heat flow passes the corrosion layer. So far, no explicit values for the thermal conductivity of the corrosion layer could be found in the literature.

2.3 Thermal contact resistance depending on joint force and surface preconditioning

The specific thermal contact resistance $r_{\mathrm{th,c}}$ is an appropriate quantity to describe the heat transfer at a thermal contact by setting the temperature difference DJ of both contact members, the apparent contact area A and the heat flow through the thermal contact in relation to each other [3].

$$r_{\mathrm{th,c}} = \frac{A \cdot \Delta \vartheta}{\dot{Q}} \tag{1}$$

The specific thermal contact resistance between a heating rod and a stock rail was already experimentally investigated with the help of an experimental model for the area, where the heating rod clamps are located [1]. In these experiments, the specific thermal contact resistance was examined as a function of the joint force with different surface treatments of the rail. A rail surface without treatment (rust), a milled rail surface and the usage of thermal-conducting paste (l = 0.5 W $(\mathrm{m\ K})^{1}$)) was thereby considered (Figure 3).

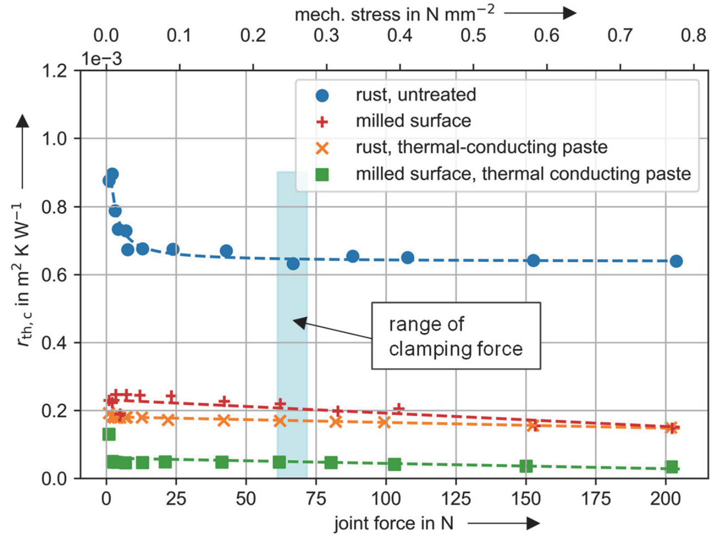


Figure 3 Specific thermal contact resistance dependent on joint force and respective mechanical stress between a heating rod and a rail for various rail surface treatments [1]

A dependency between joint force and specific thermal contact resistance was only strongly pronounced for an untreated rail surface and a joint force up to 10 N. It is shown clearly that for greater joint forces an increasing joint force decreases the thermal contact resistance only to a very small extent. However, the rail surface treatment affects the amount of the thermal contact resistance significantly (Table 1). Only that area, where the clamps are located, was considered for the measurement of the specific thermal contact resistance. The area between the clamps has also to be considered to describe the heat transfer for the real attachment of heating rod and rail.

Table 1 Specific thermal contact resistances related to the clamp area for a joint force provided by heating rod clamps for various rail surface treatments

		rail head		rail foot		heating rod	
$r_{th,c,Cl}$	$r_{th,c,mi}$	J_1	J_2	J_3	J_4	J_5	J_6
in 10^{-3} K m^2 W^{-1}		in °C					
0	0	58.3	58.3	81.2	80.7	89.0	88.7
0.05	0.05	58.2	58.2	81.1	80.7	91.3	91.0
0.20	0.20	58.1	58.1	80.9	80.5	97.5	97.2
0.90	0.90	57.5	57.5	79.9	79.5	125.4	125.1
0.65	5	55.1	55.0	77.5	74.2	158.2	254.6
0.65	50	47.7	47.4	69.2	58.4	218.7	533.4
0.65	∞	44.6	44.3	65.5	52.2	234.6	613.4
0.05	∞	47.9	47.5	72.0	56.7	122.3	572.8
0.20	5	55.5	55.4	78.8	74.5	122.6	251.5

3 Temperature distribution for various thermal contact resistances between heating rod and rail

Due to the width (w = 35 mm) of the heating rod clamps and the center-to-center distance (d = 0.3 m) of them after installation at a rail, clamps cover only approx. 12 % of the heating rod length. If varying dimensions of the contact area of both contact members were taken into account, the mechanical stress s is the appropriate reference quantity to describe the heat transfer rather than the joint force F. One of these quantities can be calculated from the other by using the apparent contact area A.

$$\sigma = \frac{F}{A} \tag{2}$$

The distribution of the mechanical stress between heating rod and rail depends on the mechanical properties of both contact members. In order to make a statement about the mechanical stress distribution, the influence contributed by the rail can be neglected, since the hardness of the rail is assumed significantly greater than the one of the heating rod. The mechanical properties, especially the rigidity of the heating rod, are unknown and processes such as production, transport, and installation can affect them. That means, the distribution of mechanical stress can vary between the heating elements and a generalised statement cannot be made. However, the two border cases are:

- a heating rod with an infinitely small rigidity
- a heating rod with an infinite rigidity

For the border case with an infinitely small rigidity of a heating rod, the mechanical stress only occurs at the clamp area. For the provided joint forces by the clamps (Figure 3) and the apparent contact area (7.5 mm x 35 mm) at the clamp, the mechanical stress results to s = 0.23 N mm^{-2}…0.27 N mm^{-2} (eq. 2). There is no mechanical stress at the area between the heating rod clamps and so the heat transfer between both contact members extents to a minimum between the clamps. Thus, the specific thermal contact resistance can be chosen according to Table 1 for the clamp area and is infinitely great for the area between the clamps. For the border case of a heating rod with an infinite rigidity, the mechanical stress is evenly distributed along the length of the contact area between heating rod and rail. According to eq. 2, the mechanical stress is s ≈ 0.03 N mm^{-2} for the entire heating rod length. For the case of an untreated rail surface and this mechanical stress, a specific thermal contact resistance $r_{th,c} \approx 0.9 \cdot 10^{-3}\ \mathrm{m}^2\ \mathrm{K}\ \mathrm{W}^{-1}$ is valid for the clamp area and the area between the clamps (Figure 3).

3.1 Model for calculating the temperature distribution

In the real application of a heating rod that is connected to a stock rail, the mechanical properties of the heating rod will be between both described border cases. A simplified FEM model can be used to determine the impact of varying specific thermal contact resistances at the clamp area and the area between the clamps on the temperature distribution in the rail and the heating rod.

Therefore, in Comsol 6.0 a separate stock rail with the length l = 0.30 m and the rail profile 60E1 [7] was set up. A heating rod was attached to the foot of the stock rail. The thermal contact resistance of the contact area between the heating rod and the rail can be parameterized differently for the clamp areas and the area between the clamps (Figure 4).

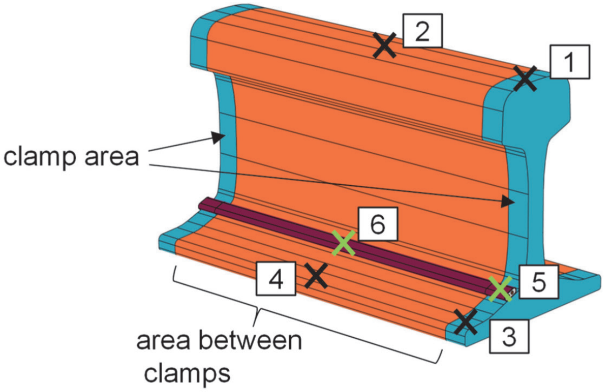
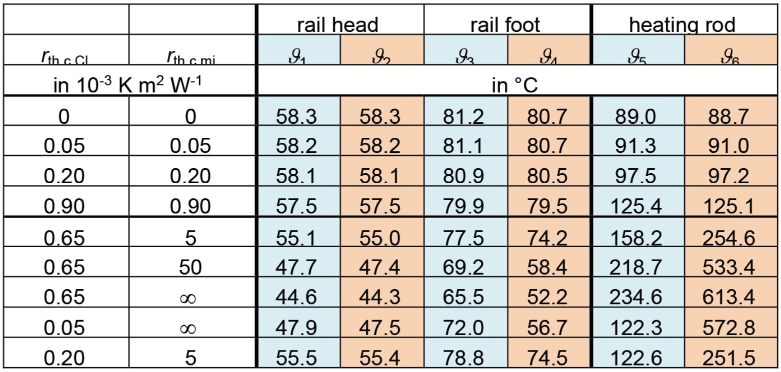


Figure 4 FEM model of stock rail and heating rod displaying the clamp area (blue) and the area between the clamps (orange) with the respective positions for the temperature measurement

In the model, the heat is generated within the heating rod. The surfaces of the rail and the heating rod emit heat by convection and radiation. The respective end faces are thermally insulated in order to simulate a homogenous model in longitudinal direction. Temperatures were measured at the head and at the foot of the rail respectively at the clamp area and at the area between the clamps. Additionally, the temperatures on top of the heating rod were evaluated at both areas. Initially, an ideal case, was calculated that serves as a reference (Table 2). In this ideal case, the specific thermal contact resistance at the clamp area ($r_{th,c,Cl}$) and at the area between the clamps ($r_{th,c,mi}$) are both set to zero.

Table 2 Temperatures J at the rail and the heating rod (Figure 4) calculated by a FEM model for various specific thermal contact resistances at the clamp area $r_{th,c,Cl}$ and at the area between the clamps $r_{th,c,mi}$ for a heating power P = 333 W m⁻¹ and an ambient temperature J_a = 20 °C



		rail head		rail foot		heating rod	
$r_{th,c,Cl}$	$r_{th,c,mi}$	ϑ_1	ϑ_2	ϑ_3	ϑ_4	ϑ_5	ϑ_6
in 10^{-3} K m² W⁻¹		in °C					
0	0	58.3	58.3	81.2	80.7	89.0	88.7
0.05	0.05	58.2	58.2	81.1	80.7	91.3	91.0
0.20	0.20	58.1	58.1	80.9	80.5	97.5	97.2
0.90	0.90	57.5	57.5	79.9	79.5	125.4	125.1
0.65	5	55.1	55.0	77.5	74.2	158.2	254.6
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0.20	5	55.5	55.4	78.8	74.5	122.6	251.5

If there is an ideal heat transfer from the heating rod into the rail (no thermal contact resistances), the temperatures are at the head of the rail (J_1, J_2) approx. 58 °C, at the foot of the rail (J_3, J_4) approx. 81 °C and at the heating rod (J_5, J_6) approx. 89 °C. For a milled surface and / or with a thermal-conducting paste treated surface and an equal specific thermal contact resistance ($r_{th,c,Cl}$ = $r_{th,c,mi}$ = 0.05 ·10^3 K m² W⁻¹; $r_{th,c,Cl}$ = $r_{th,c,mi}$ = 0.2 ·10^{-3} K m² W⁻¹) the rail temperatures differ hardly from the ideal case. The temperatures at the heating rod are increased by approx. 10 K. The temperature distribution for an untreated rail and an infinitely rigid heating rod ($r_{th,c,Cl}$ = $r_{th,c,mi}$ = 0.9 ·10^{-3} K m² W⁻¹) only differ in the heating rod temperatures ($J_5 \approx J_6 \approx$ 125 °C) from the previously considered cases.

For all the cases considered so far, a treatment of the rail or an increase of the force provided by the clamps would generate little added value regarding the temperature distribution.
For a lower rigidity of the heating rod, and thus a lower mechanical stress in the area between the clamps, greater specific thermal contact resistances have to be considered between the clamps. The calculation results show that the temperature on the heating rod rises significantly between the clamps if the specific thermal contact resistance increases at this area (J_6 ≈ 254 °C for $r_{th,c,mi} = 5 \cdot 10^{-3}$ K m^2 W^{-1} and $r_{th,c,Cl} = 0.65 \cdot 10^{-3}$ K m^2 W^{-1}). The decreasing of the rail temperatures compared to the ideal case is only weakly pronounced (max. approx 6 K for J_4). The temperature distribution of this case is close to that of practical measurements at rail and heating rod. If the rail surface will be milled or equipped with a thermal-conducting paste in the clamp area, so that $r_{th,c,Cl} = 0.20 \cdot 10^{-3}$ K m^2 W^{-1}, there is no siginificant change in the rail temperature. Only the heating rod temperature at the clamp area benefits from this reduced specific thermal contact resistance.

4 Conclusion

According to the results of the FEM heating calculation of a heating rod and a stock rail, it can be stated that the rail temperature is not sensitive to the specific thermal contact resistance. Even for great specific contact resistances between the clamps $r_{th,c,mi} = 5 \cdot 10^{3}$ K m^2 W^{-1} the rail temperatures are only reduced to a small extent of 6.5 K at the foot of the rail. This is due to a fact that the large cross section of the rail is capable to conduct the heat lonitudinally with a few temperature difference over length. So a moderate thermal contact at the clamp area is sufficient to supply the rail with heat. Cumbersome rail treatments like milling or using a thermal-conducting paste hardly improve the temperature distribution at the rail.
The temperatures on the heating rod, on the other hand, show a strongly pronounced dependency on the specific thermal contact resistance. Very high temperatures at the heating rod can lead to a malfunction of this part. This risk applies in particular for the area between the clamps, due to the undefined mechanical properties of the heating rod. A reduction of the center-to-center distance of the clamps and the application of wider heating rod clamps reduce the proportion of the area between the clamps. Subsequently, the risk of a very poor thermal contact can be significantly reduced, and thus also the temperatures on the heating rod and a related malfunction.

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