CETRA2022 11-13 May 2022, Pula, Croatia
7th International Conferenceon Road and Rail Infrastructure

INVESTIGATIONS ON THE INFLUENCE OF MECHANICAL AND THERMAL LOAD ON THE CLAMPING FORCE OF HEATING ROD CLAMPS

Markus Schladitz, Max Huter, Robert Adam, Stephan Schlegel
Technische Universität Dresden, Institute of Electrical Power Systems and High Voltage Engineering, Germany

Abstract

During wintertime, switch point heating systems are utilized for railway switch points. They are aiming to prevent snow and ice from accumulating between the moveable components of a switch point, and thus, maintain a faultless setting of the switch point. Electrical heating rods are a frequently used application of switch point heating systems. Clamps made of spring steel often realize the mounting of the heating rod to the rail. The clamps are set in a common distance of 30 cm along the rail. Considering a section reaching from the middle of one clamp along the rail to the middle of the consecutive clamp, previous investigations showed that significant higher temperatures occur at the heating rod in the middle of this section than at its ends. This suggests that the heat transfer between heating rod and rail is higher at the clamps than in between. Consequently, there is a correlation between the contact force of heating rod and rail, and the heat transfer. Another assumption is that the presence of mechanical and thermal load can reduce the contact force provided by the clamps over time. In order to evaluate these correlations, new clamps were mechanically loaded by bending and additionally heated to 150 °C or 200 °C. The results show that considering a stress time up to 2000 h the thermal load for itself has no significant influence on the clamping force. The mechanical load, however, can decrease the clamping force by 7 % and the combination of mechanical and thermal load can decrease it by 13 %. This article explains the experimental setup for this investigation and the causes that lead to the reduction of the clamping force.

Keywords: switch point heating, heating rod clamps, mechanical and thermal load, clamping force reduction, heat transfer

1 Introduction

Switch points are an essential part of the railway infrastructure, since they enable trains to change their tracks without interrupting their journey. In wintertime, snow and ice might accumulate between the moveable components of switch points and prevent their proper operation. This circumstance causes delays and cancellations of train services, and thus, requires better prevention. Switch point heating systems aim for melting ice and snow, and electrical heating rods constitute a commonly used technical application. In this case, an electrical current flows through a wire, generating thermal energy. The wire is electrically insulated and enclosed in a metal jacket. Metal clamps press the heating rod against the rail and ensure the mechanical contact between both components. The clamps are usually set in a distance of 30 cm to each other along the rail.

DOI: https://doi.org/10.5592/CO/CETRA.2022.1377

Previous thermal inspections with a thermal imaging camera showed a significant temperature difference of approx. 55 K in longitudinal direction of the heating rod (Figure 1). In order to reach a uniform emissivity of the heating rod, the heating rod was painted with a special emissivity varnish.

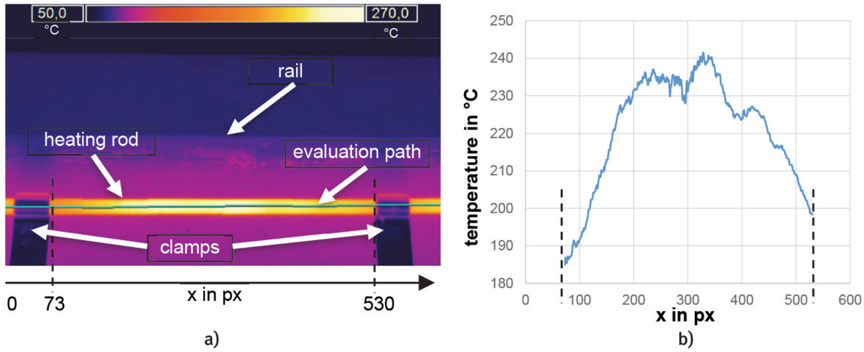


Figure 1 a) Thermal image of heating rod and stock rail at an ambient temperature of 22 °C for a heating power of 300 W m^{-1} and an emissivity of 0.87; b) related temperature at the heating rod along the green horizontal evaluation path dependent on the respective pixel in the thermal image

Assuming a constant specific electrical resistance and cross section of the wire, the different temperatures of the heating rod are the result of a various magnitude of the heat transfer resistance between heating rod and rail. The higher the heat transfer resistance is, the less heat passes the interface between two bodies. Hence, it affects higher temperatures at the respective locations. That leads to the conclusion that the contact force in the middle between two clamps is significantly lower than in the area next to a clamp.
In order to understand the heat transfer from the heating rod into the rail better, the general objective is to determine the dependency between the contact force and the heat transfer resistance. To achieve that, the first step is to analyze the applied clamp force and its influence factors. The clamp force constitutes the maximum occuring force between the heating rod and the rail. Since the heating rod clamps are thermally loaded and mechanically stressed during the operation, the influence of these stresses has to be evaluated separately to investigate the effect of ageing processes on the clamping force. The results of those investigations will be shown in the following.

2 Fundamentals

2.1 Fundamentals of metallurgy

The atomic cores of metals are arranged in a lattice structure while the valence electrons are freely moveable as electronic gas (Figure 2). Various lattice defects occur in real lattice structures, and can affect the properties of the material. The defects are divided into point defects, line defects and planar defects. Point defects only affect one point in the lattice, whereas line defects like edge and screw dislocations affect one-dimensional rows. They can move through the lattice if a force is applied, and thereby, cause the deformation of the body. Beside possible external stresses that affect a material, there are residual stresses that can improve or impair the resilience to external loads. [1]
External mechanical loads that are applied to a material are tensile stresses, compressive stresses and shear stresses. In order to characterize the material behavior under these loads, various tests can be performed. The tensile test is an essential part of material testing and determines the material resilience to tensile forces. For materials without a pronounced

yield strength, the dependency between tension and elongation has a characteristic correlation (Figure 2). The left area of the characteristics illustrates the linear elastic deformation, whereas the right area shows plastic deformation. However, it is not possible to separate elastic and plastic deformation for tensile tests clearly. The elastic deformation includes the elongation of atomic bonds within a material without an irreversible displacement of the atomic structures. The plastic deformation, in contrast, occurs if atomic bonds cannot resist the applied stress anymore and so dislocations glide along the material. [1][2]

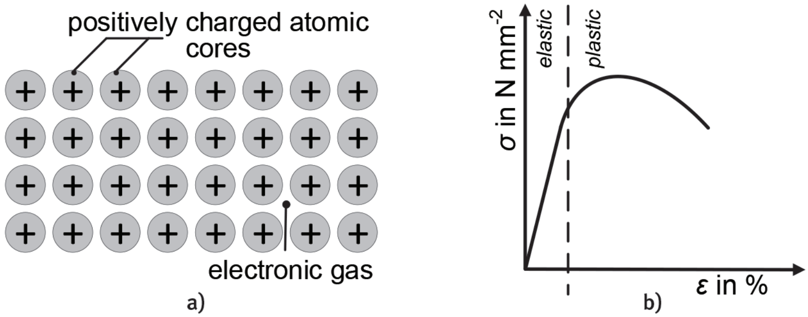


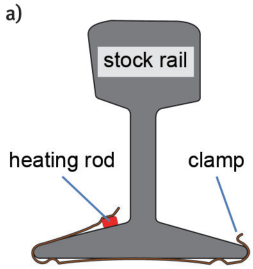
Figure 2 a) Lattice structure of metals; b) Stress-strain-diagram for materials without pronounced yield strength [1]

2.2 Relevant ageing processes

Recovery is the metallurgical process of the removal and relocation of point or line defects. This leads to a reduction of residual stresses over time, also known as stress relaxation. Thereby, the total elongation stays constant. If the external load stays constant, a time-dependent plastic deformation, called creeping, takes place. [1]
Generally, the attempt is to design components in such a way that creep and stress relaxation only occur to a very small extent in order to keep mechanical properties approximately constant over time. However, thermal and mechanical load can accelerate ageing processes.

3 Experimental setup

In order to investigate the influence of mechanical and thermal load on ageing processes and thereby on the clamping force, the clamping force has to be measured after various periods of exposure to the respective load. A classic tensile test for material testing is modified for this purpose. The elongation correlates to the bending of the clamp and the tension correlates to the tensile force that it requires. Even though there is no actual stretching of the material investigated in this application, the tensile test delivers the corresponding force value to the respective clamp deflection.
3.1 Description of the test specimens
A total of 85 newly manufactured clamps, made of spring steel, were examined to receive an understanding about the influence of mechanical and thermal load to the clamping force. The clamps are designed to attach a usual switch point heating rod with a cross section of 13 mm x 5.5 mm to the foot of a stock rail type 60 E1 (Figure 3). The clamps have a width of 35 mm and a thickness of 1 mm.



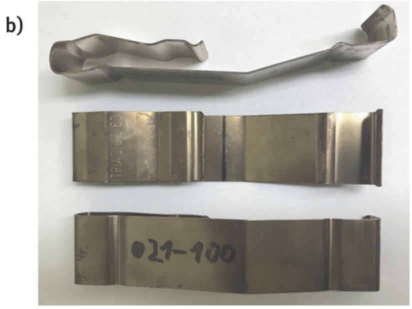


Figure 3 a) attachment of heating rod to the stock rail with the clamp; b) view on a separate clamp in unmounted state

3.2 Description of the experimental plan

The clamps were kept under the respective loads and after certain time points, the tensile force and the respective bending of the clamp were measured. It was not possible to measure those quantities while the clamps were still in the loaded state, so they had to be relieved of the respective loads during measuring. The clamps should be investigated for different mechanical and thermal loads. The mechanical load was realized by storing the clamp bended like in the installed position. Previous investigations on switch point heating showed that temperatures of 200 °C on the surface of the heating rod are entirely possible [3]. Another thermal load of 150 °C was supposed to point out the dependency of ageing processes on the magnitude of temperature. The combinations of those conditions led to six different loading groups (Table 1). The time interval of the load between the measurements was initially chosen to be smaller and increased in the course of the investigations. The final measured values were recorded after 2000 h of loading.

Table 1 Allocation of the number of clamps to the respective loading groups

Group	**1**	**2**	**3**	**4**	**5**	**6**
Mechanical	no load	installed	no load	installed	no load	installed
Thermal	room	room	150 °C	150 °C	200 °C	200 °C
No. of clamps	10	15	15	15	15	15

3.3 Measurement of tensile force and consequential bending

The modified tensile tests were performed on ZwickRoell's universal testing machine with an Xforce K load cell. A specially manufactured fixture ensured that the clamps were locked in place during the test and limited any transverse forces to a minimum.
Based on the geometry of the foot of the stock rail, it was possible to determine how large the bending of a clamp is in the installed condition. To represent additional bending during assembly, the clamp was deformed in the modified tensile test to a maximum bending that was 3 mm greater than the bending in the mounted condition.

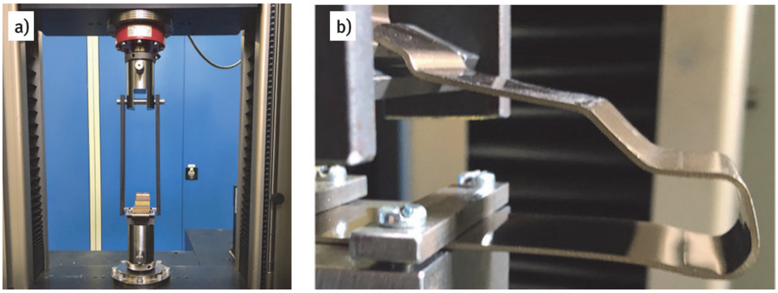


Figure 4 General overview of the measurement setup; b) Close-up of a clamp during the test procedure

Since respectively the same clamp will be measured at different stages, it had to be ensured that the measurement itself had no impact on the material properties. That means, the modified tensile test had to stay in the range of elastic deformation all the time. In order to evaluate this circumstance, a selection of clamps went through the measurement procedure 50 times in succession. The correlation between applied force and bending stayed the same, so it can be assumed that the measurement did not affect the properties of the clamps lastingly.
Additionally, there is only a meaningful comparison between clamps loaded by different conditions possible if a normal distribution of the clamping force exists in the installed condition. A Kolmogorov-Smirnov test confirmed a normal distribution after the respective tensile force of each clamp was measured initially.

4 Analysis of the test results

The investigation showed that the dependency between force and machine movement differed for the sub processes of force increase and force decrease. This hysteresis could be examined for every specimen, whereby its magnitude differed. Considering a single specimen of the group with mechanical load and 200 °C, a significant displacement of this hysteresis along the axis for the machine movement is notable (Figure 5).

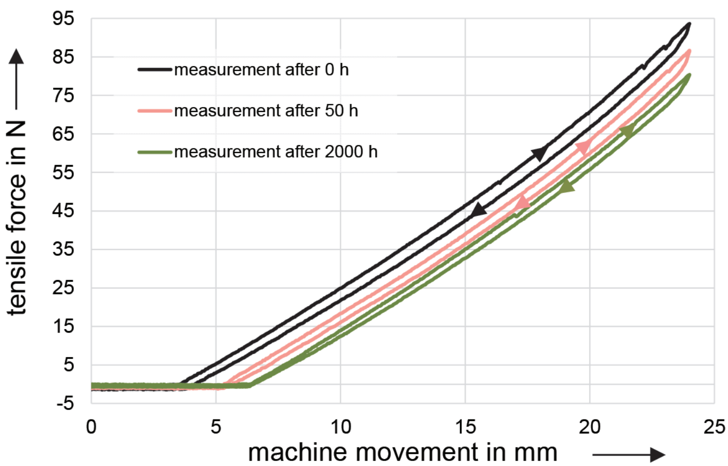


Figure 5 Exemplary correlation between tensile force and machine movement of the same specimen that was stored in the mounted position at a temperature of 200 °C

It stands out that the curves are almost parallel. The testing program used the same parameters regardless of already passed duration of load. Therefore, the starting position stayed the same for all tests. The longer this specimen was mechanical and thermally loaded, the longer the traverse path is until the tensile force starts increasing. This indicates, plastical deformation has taken place and the clamp is bent up due to the prestress.
In order to analyze the impact of the different combinations of stress, measured forces at the installation position were averaged respectively for each loading group (Figure 6).

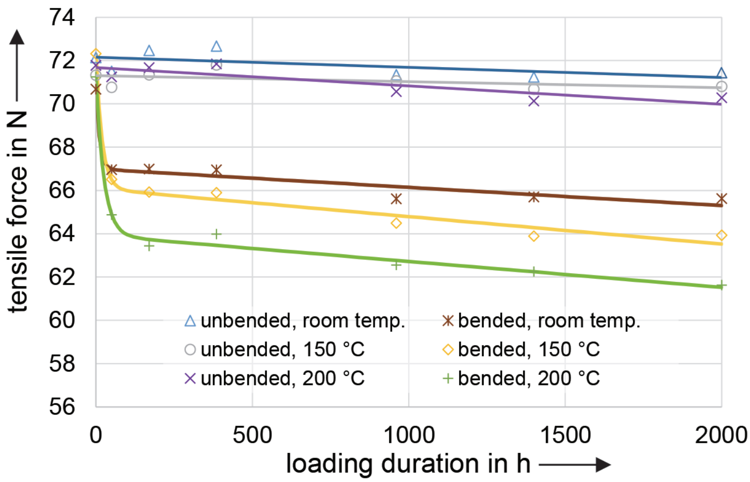


Figure 6 Time course of tensile forces for different combinations of mechanical and thermal load at the installed state of the clamp

Obviously, the clamp force will significantly reduce over time as long as the clamps are mechanically loaded. An increase in temperature exclusively does not affect the clamp force. However, the clamp force reduces more over time, the higher the temperature load is. The greatest force decrease occurred for mechanically loaded clamps that were stored at 200 °C (Table 3). The major reduction happens already in the first hours after the load start and decreases in the course of time.

Table 2 Reduction of clamp force after the respective group was loaded for 2000 h

Group	1	2	3	4	5	6
Force reduction [%]	1.0	7.1	0.7	11.6	2.1	13.5

Recovery is one cause for the reduction in force. It eliminates lattice defects, thereby reduces residual stresses and leads to stress relaxation. The detected plastic deformation is an indicator that creep processes are also involved. Dislocations glide through the lattice and deform the material. Stress relaxation and creep appear together and cannot be sharply separated from each other in the examinations. Additionally, high temperatures accelerate the ageing processes.

5 Conclusion

This investigation showed that ageing processes of clamps for electrical point heating rods can be significantly accelerated if the clamps are mechanically loaded. The ageing caused by external stress can be amplified with thermal load. Creep and stress relaxation cause a clamp force reduction of up to 13.5 % already after 2000 h load time.
Subsequently, this investigation should be continued over a longer time period, since heating rod clamps are usually used for years. In the next step, it is important study the heat transfer from the heating rod into the rail depending on the contact force and the surface conditioning. Combining the results of the investigation described in this paper with the planned ones, a statement can be made, to what extend the heat transfer between heating rod and rail will impair due to ageing. Furthermore, it can then be described whether the clamping force of currently used clamps is sufficient for the desired heat transfer or has to be increased, thus increasing the reliability of point heating systems.

References

[1] Bargel, H. J., Schulze, G.: Werkstoffkunde, 12th edition, pp. 1-13, 2018.

[2] Rösler, J., Harders, H., Bäker, M.: Mechanisches Verhalten der Werkstoffe, 4th edition, 2012.

[3] Schladitz, M., Adam, R., Großmann, S.: Calculation of the temperature distribution in heated switch points, 6th International Conference on Road and Rail Infrastructure – CETRA 2020*, online, 20-21 May 2021.