The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 4.13
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.4.13

Wear model for pantograph-catenary interaction under Norwegian conditions

S. Derosa[1], P. Nåvik[1], G. Bucca[2], A. Collina[2], A. Rønnquist[1]

[1]Dept.of Structural Eng., NTNU Trondheim, Norway
[2]Dept. of Mechanical Eng., Politecnico di Milano, Italy

Abstract

Electric railways are nowadays the state-of-the-art for what concern the design of high-speed lines. The research on this particular segment of railways is focused on the pantograph-catenary interaction because this is what limits the maximum allowed speed. Within this field of research, the topic of the wear of the components involved in the sliding contact attracted the attention of rail operators, due to the possibility of reducing costs and failures once this phenomenon is better understood. Multiple studies investigated the effects on the wear of materials, current intensity, train speed, contact force, arcs and heat generated at the contact surface. All these studies pointed out interesting characteristics of this phenomenon, namely its high dependency on operational parameters and the benefits of having results from laboratory tests, given the inherent difficulty on retrieve enough reliable data from field measurements.
In this work, results from dedicated laboratory tests at Politecnico di Milano are used to create a model for the contact wire wear and a model for the contact strip wear. The two models are representative of the conditions currently in use within the Norwegian Railway Network. Furthermore, the laboratory tests allowed to explore parameter values that might be used for future applications. Further test with more extreme values allowed to extend the validity of the study beyond the needed range, so to have a robust prediction on the created models. The models were generated by fitting an equation that includes the main contributions to the wear (mechanical, electrical, arcs) to the test results. Considerations regarding the area of influence of each contribution are also possible. This allows to understand, given the operating conditions, which kind of wear to expect. Furthermore, the models can be used to estimate the wear both

on new lines, integrating it with the simulation tool used for the study of the catenary dynamics, and on existing lines, applying the contact force and electric current intensity data recorded from the field measurements.

Keywords: Pantograph-catenary interaction, Contact wire wear model, Contact strip wear model, Wear prediction.

1 Introduction

Electric railways are nowadays the state-of-the-art for what concern the design of high-speed lines. The research on this particular segment of railways is focused on the pantograph-catenary interaction for good reasons: this is what limits the maximum speed allowed on a determined line [1]. While large part of the studies aim at the creation and validation of numerical or hybrid models for the simulation of the catenary dynamics when there is an interaction with a passing train [2], another topic attracted the interest of the researchers in relatively recent years: the modelling of the collector / contact wire wear. The main reason is to be searched in the contribution of optimizing the Life Cycle Costs of the involved components and, in the end, of the whole system [3]. Multiple studies have been carried out in order to investigate the effects on the wear of used materials [4], current intensity, train speed [5], contact force [6], arcs (both in DC [7] and AC [8]) and heat generated at the contact surface [9].

All of these studies pointed out interesting characteristics of this phenomenon. Among the others, two are worth of notice for the current work. The first one is that the wear is highly dependent on operational parameters [10], giving plenty of reasons for an investigation towards extreme values of these parameters, in particular when it comes to studies for new lines. The second point worth of notice is that this field, above all the others, greatly benefits from properly designed laboratory testing, since having data from field measurements is time costly and anyway with a low reliability. For this reason, many test rigs have been built during the years, each of them with a purpose in mind.

In this work, the test rig at Politecnico di Milano has been used [11] with the aim of building a wear model for the contact wire and one for the contact strip valid for the condition in use within the Norwegian Railway Network. The tests have been designed in order to investigate the wear both with the parameter values currently adopted on the main electrified lines, and the ones that are taken into account for future applications. Further test with more extreme values allowed to extend the validity of the study beyond the needed range, so to have a robust prediction on the created model.

2 Methods

In order to create a model representative of the chosen conditions, a sequence of tests has been performed at the wear test rig at Politecnico di Milano. For each of the test a set of values for the current, the train speed and the uplift force was chosen, so to represent current and possible future conditions of operations. The contact wire is a CuAg 100 mm^2, the same used in the Norwegian Railway System 20 catenary systems. The contact strip is a copper impregnated carbon strip, as in use on the latest Class 74/75 Stadler FLIRT EMUs.

For each test, measurements on the wire thickness along its length and on the contact strip weight has been performed before and after the tests, so to evaluate the absolute wear and, knowing the run distance, the wear ratio. This last parameter is expressed in volume of material removed per kilometre when evaluating the contact strip behaviour, and in volume of material removed per million collector passages when it comes to the contact wire.

All the results obtained from these tests were then used to fit a parametric model that takes into consideration the three main effects that influence the wear: mechanical, electrical, arcs. This model is as per [12], but this time applied to an AC case, with specific results for Norwegian conditions [13].

In order to fit the model the least square method has been applied. Given the complexity of the model and the high number of parameters involved, a sensitivity analysis for each of the chosen parameter has been run. This allowed having a better understanding of how much each parameter, hence, each of the mentioned effects that influence the wear, contributes to the final result.

Further analysis on the relation between the contact force and the contact resistance has been performed. These were needed in order to evaluate the relation between the electrical component of the fitting formula and the applied contact force [14].

3 Results

The procedure for the fitting of the equation on the experimental results produced two wear models, respectively for the contact wire and the contact strip.

Figure 1a shows the model for the contact wire wear compared to the corresponding measured data. Force values are between 40 N and 80 N, and current intensity values are between 250 A and 500 A. These values are intended per collector, so, in case of pantograph mounting multiple collectors, they have to be adjusted accordingly. For this model it is possible to notice that the mechanical component is predominant around high contact force and low current values, while the electrical component is predominant around high current and low contact force values. In this range of values, the mechanical contribution lowers mainly due to the effect of current lubrication, where the heat generated by the current melts the carbon on the contact strip and create a layer of lubricant between the two sliding components. This means that it possible to find an optimal point where the wear is minimized with the right choice of current intensity and uplift force.

Figure 1b shows the model for the contact strip wear compared to the corresponding measured data. The range of the operating parameters is the same as in Figure 1a. Within this range there is no minimum point for the wear model that can give a clear optimal set of operating parameters to minimize wear in the contact strip. The reason is linked with the different effects that the current lubrication has on the wire and on the strip. The lubrication that allows to protect the wire is made with melt carbon from the contact strip, thus increasing the wear in the contact strip itself, especially for high values of current intensity. The trend indicates that a low current and high contact force is the direction to take to reduce wear in the contact strip. Furthermore, a dependency of the contact strip wear from the lateral speed of the contact point due to thermal effects was found [15]. Figure 2 shows how the electrical component of the wear increases when the speed at which the contact point moves across the contact strip decreases.

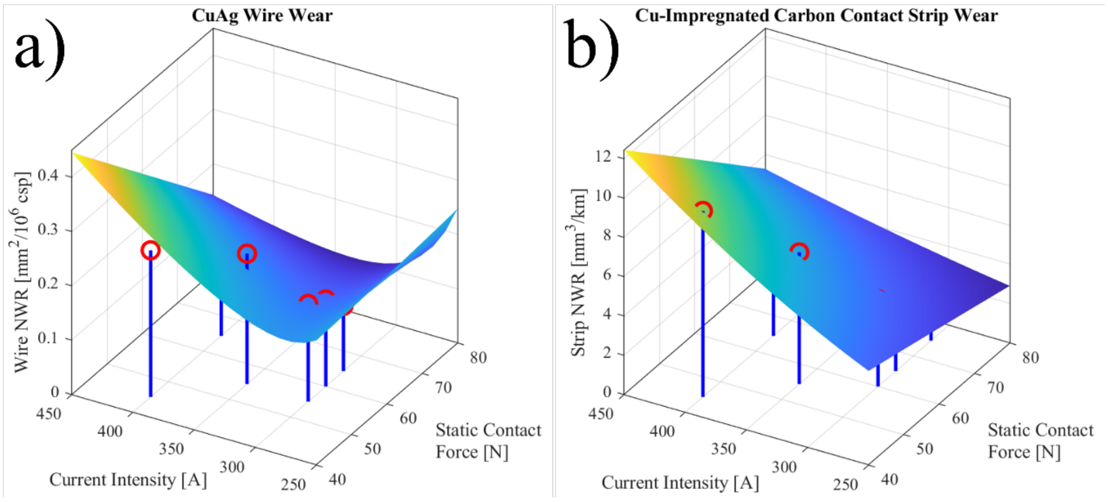

Figure 1: NWR surface and comparison with the measured data for the contact wire (a) and contact strip (b).

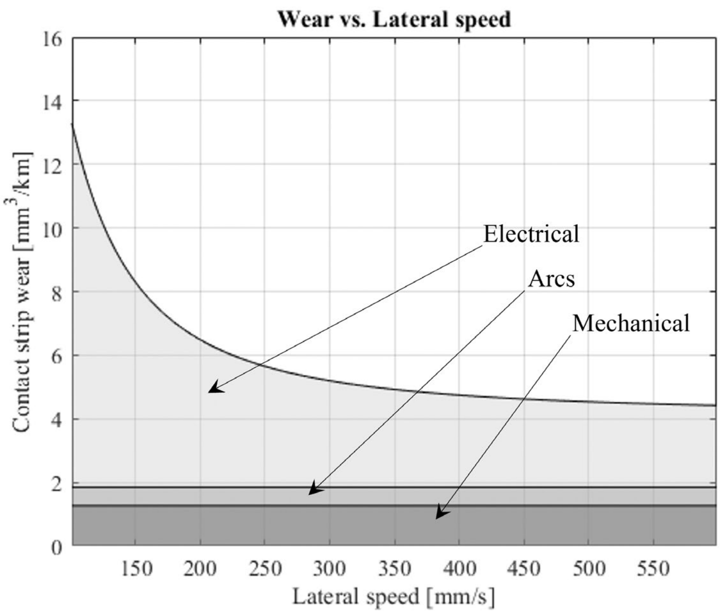

Figure 2: contact strip wear dependency on the lateral speed of the contact point between pantograph and contact wire.

4 Conclusions and Contributions

The topic of the wear in the pantograph-catenary interaction is attracting the attention of the research because of its contribution to the lowering of Life Cycle Costs in the electric railway field. From this work a contribution to this in the electric railways that operate with conditions similar to the ones applied in Norway can be provided.

A model for the contact wire wear and a model for the contact strip wear are presented. They are a useful tool for the estimation of the wear at given operating conditions. In used together, the models can be used to find an optimal operating point that satisfies both the infrastructure and the train owners.

Furthermore, thanks to the process followed to build the model, it is also possible to split the estimated wear in the three main components that are thought to be the ones that most contribute to the wear: mechanical, electrical, arcs. In this way, a better understanding of which characteristics of the components that realize the contact should receive more focus in case of further development is possible.

In conclusion, this work allows a better understanding of the wear phenomenon from the point of view of the applied parameters of contact force and electric current intensity.

References

[1] F. Kiessling, R. Puschmann, A. Schmieder, and E. Schneider, *Contact Lines for Electric Railways*, 3rd ed. Erlangen: Publicis, 2018.

[2] S. Bruni, G. Bucca, M. Carnevale, A. Collina, and A. Facchinetti, "Pantograph–catenary interaction: recent achievements and future research challenges," *Int. J. Rail Transp.*, vol. 00, no. 00, pp. 1–26, 2017, doi: 10.1080/23248378.2017.1400156.

[3] J. Wilde, A. Rukwied, K. Becker, U. Resch, and B. Zweig, "LCC Optimisation in the Design Process of Catenaries of Electrical Train Systems," 1997.

[4] H. Borgwardt, "Verschleiß Verhalten des Fahrdraht der Oberleitung," *Elektrische Bahnen*, vol. 87, no. 10, pp. 287–295, 1989.

[5] D. Klapas, F. A. Benson, and R. Hackam, "Simulation of wear in overhead current collection systems," *Rev. Sci. Instrum.*, vol. 56, no. 9, pp. 1820–1828, 1985, doi: 10.1063/1.1138101.

[6] D. Klapas, F. A. Benson, R. Hackam, and P. R. Evison, "Wear in simulated railway overhead current collection systems," *Wear*, vol. 126, no. 2, pp. 167–190, 1988, doi: 10.1016/0043-1648(88)90136-6.

[7] S. Kubo and K. Kato, "Effect of arc discharge on wear rate of Cu-impregnated carbon strip in unlubricated sliding against Cu trolley under electric current," *Wear*, vol. 216, no. 2, pp. 172–178, 1998, doi: 10.1016/S0043-1648(97)00184-1.

[8] G. X. Chen, H. J. Yang, W. H. Zhang, X. Wang, S. D. Zhang, and Z. R. Zhou, "Experimental study on arc ablation occurring in a contact strip rubbing against a contact wire with electrical current," *Tribol. Int.*, vol. 61, pp. 88–94,

2013, doi: 10.1016/j.triboint.2012.11.020.

[9] H. Nagasawa and K. Kato, “Wear mechanism of copper alloy wire sliding against iron-base strip under electric current,” *Wear*, vol. 216, pp. 179–183, 1998, doi: 10.1016/S0043-1648(97)00162-2.

[10] K. Becker, A. Rukwied, W. Zweig, and U. Resch, “Simulation of the wear behaviour of high-speed over-head current collection systems,” *Trans. Built Environ.*, vol. 17, pp. 281–290, 1996.

[11] M. Bocciolone, A. Collina, G. Bucca, and F. Mapelli, “A Test Rig for the Comparative Evaluation of the Performance of Collector Strips,” *Proc. Railw. Eng. Conf.*, 2004.

[12] G. Bucca and A. Collina, “Electromechanical interaction between carbon-based pantograph strip and copper contact wire: A heuristic wear model,” *Tribol. Int.*, vol. 92, pp. 47–56, 2015, doi: 10.1016/j.triboint.2015.05.019.

[13] S. Derosa, P. Nåvik, A. Collina, G. Bucca, and A. Rønnquist, “A heuristic wear model for the contact strip and contact wire in pantograph – Catenary interaction for railway operations under 15 kV 16.67 Hz AC systems,” *Wear*, vol. 457, p. 203401, 2020, doi: 10.1016/j.wear.2020.203401.

[14] G. Bucca, A. Collina, R. Manigrasso, F. Mapelli, and D. Tarsitano, “Analysis of electrical interferences related to the current collection quality in pantograph-catenary interaction,” *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit*, vol. 225, no. 5, pp. 483–499, 2011, doi: 10.1177/0954409710396786.

[15] S. Derosa, P. Nåvik, A. Collina, G. Bucca, and A. Rønnquist, “Contact point lateral speed effects on contact strip wear in pantograph – catenary interaction for railway operations under 15 kV 16.67 Hz AC systems,” *Wear*, vol. 486–487, p. 204103, Dec. 2021, doi: 10.1016/j.wear.2021.204103.