STRAHOS 2022
19th Seminar of Track Management
13 and 14 October 2022, Poprad, Slovakia

Special Session ‘New Railway Structures’

SUGGESTION FOR AN APPROACH TO GEOMETRY OPTIMIZATION OF SWITCH FROGS USING MEASUREMENT DATA AND CALCULATION MODELS

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1. Introduction

Rising travel speeds and axle loads in rail traffic have been leading to increasing dynamic loadings of the railway superstructure in the past decades. This increase takes effect especially in switch areas, as the common construction of switches (with a rigid frog) is predisposed for evoking high dynamic loads [1]. Those appear concentrated in the region of the frog and wing rail. The high concentration of the loading leads not only to a continuous wear of the switch elements, but also to sudden rail defects due to rolling contact fatigue (RCF) [2], as depicted in *figure 1*.

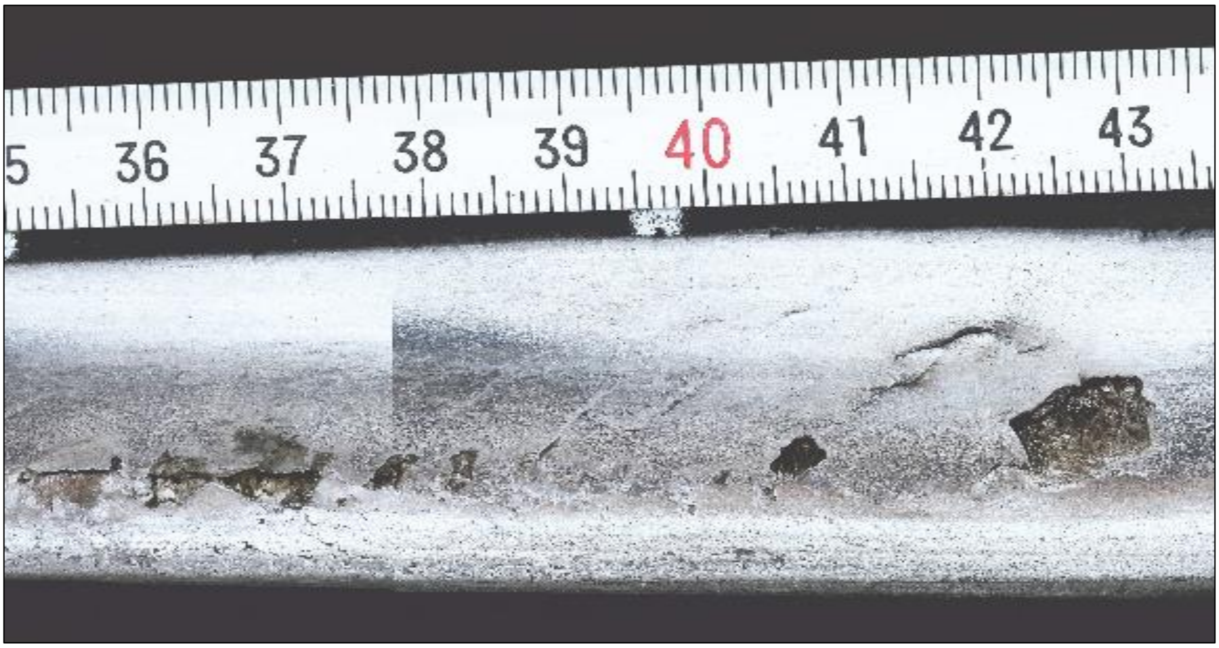

Fig. 1 – Sudden rail defect on the running surface of a switch frog (picture: [2]*)*

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The switch area is generally characterised by a low degree of automation in inspection and maintenance, which is due to the complex construction of the switch. Regarding material fatigue, no reliable instrument for evaluating its progress has yet been developed. Thus, in current practice, predictions concerning the appearance of RCF failures are conducted by experts, based on their subjective visual perception and experience.

As a consequence of the subjective evaluation of the state of switch elements, their possible lifetime is supposedly often undercut, meaning that maintenance works are conducted before they are actually required. On the other hand, the overestimation of the remaining lifespan of a switch element leads to the rail defects discussed above, causing severely increased stress on vehicles and railway superstructure. A better knowledge concerning the progress of rolling contact fatigue on the running surface of switch elements could reduce the effect of those misjudgements and thus help to reduce the lifecycle costs of the switch.

Regarding the high maintenance costs for switches compared to open track[1] [3] and the high amount of switches in a whole railway network[2] [4], even a minor advance in the topic would provide substantial economic benefits.

2. Lifetime variability of switch frogs

In 2004, the German railway company DB AG established a test track for switch frogs within the running railway network near the city of Hannover. Up to 19 isolated switch frog samples (as seen in *figure 2*) can be installed at the same time and exposed to identical operational load while being subjected to intense measurement campaigns [5].

More than 15 years of experience at the test track showed, that the lifetimes of the observed switch frogs vary in a huge range (from about 30 up to about 250 million tons of operating load). The mentioned lifetime can be seen as a consequence of the interaction of strain and resilience of the switch frog, which are both varying factors (1). Thus, a long lifetime can either be the consequence of low strain, high resilience, or both:

$$lifetime \uparrow \;\Leftrightarrow\; \frac{resilience \uparrow}{strain \downarrow} \tag{1}$$

The resilience is a variable dependent on the switch frog material and has already been studied in the context of the project. An optimisation of the switch frog material, providing an enhancement of switch frog lifetimes, has successfully been realised [4, 6].

However, even within the same material (R350 HT, standard material for switch frogs in the German Railway network), a huge variance of switch frog lifetimes (from about 30 up to still more than 200 million tons) can be observed. This variance of switch frog durability by a factor of more than six has to be traced back to the influence of varying strain. As the operational load of the examined switch frogs is identical, the variance of strain is a consequence of the geometric and stiffness properties of the switch, as well as the stiffness properties of the substructure.

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[1] The maintenance cost of switches amount to more than 25 % of the total maintenance cost of a railway line.

[2] In 2014, the network of the German Railways (DB AG) included about 72.500 switches, of which 30.000 were situated in highly frequented tracks with extensive loadings.

Fig. 2 – Test track for switch frogs near Hannover (picture: [7])

3. Measurement systems for switch frogs

For a deeper research on the problem, the measurement system ESAH-M[3] (*figure 3*, left) is being applied to obtain specific measurement data. The system provides records of the frog and wing rail accelerations during trains' passage (*figure 3*, right), as well as information on the touchdown positions of the wheels on the frog rail. At the same time, geometric data of the switches is collected using the measurement systems MiniProf Switch [10] and Scorpion[4] (*figure 4*). While MiniProf is a handheld, mechanical measuring device that delivers two-dimensional profiles of the frog and wing rails, the laser measuring device Scorpion provides three-dimensional geometric data of the switch frog. Both systems can be used to obtain a three-dimensional model of the switch frog area, as depicted in *figure 5*.

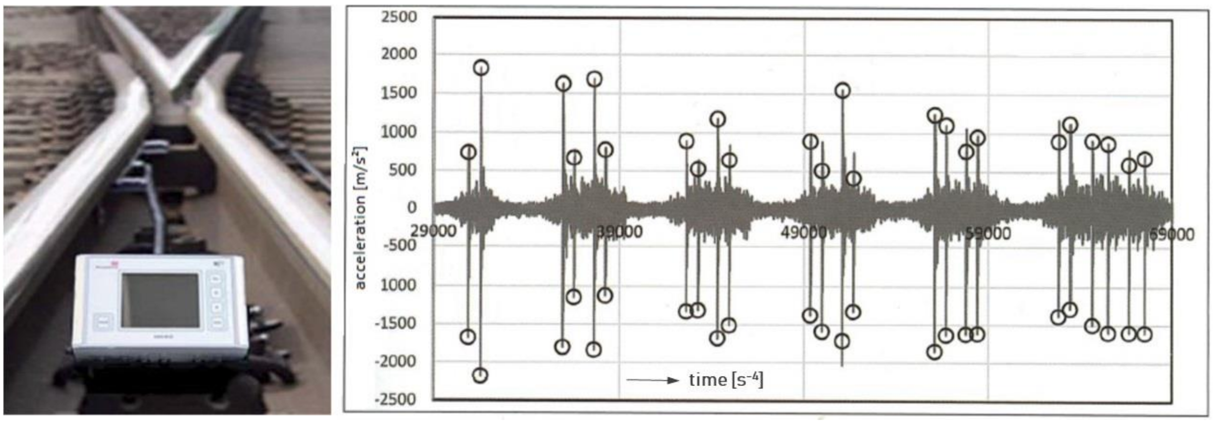

Fig.3 – Left: the measurement device ESAH-M (picture: [8]), right: example for the measured accelerations of a switch frog (passage of 24 axles) (picture: [5])

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[3] "Electronic System Analysis in the Frog Area – Mobile Version"

[4] A laser measuring system for scanning switch frog geometries, developed in the cooperation of DB Systemtechnik GmbH, Bahntechnikerring 74, 14774 Kirchmöser, Germany and P.U.T. GRAW Sp. z o.o., ul. Karola Miarki 12, 44-100 Gliwice, Poland

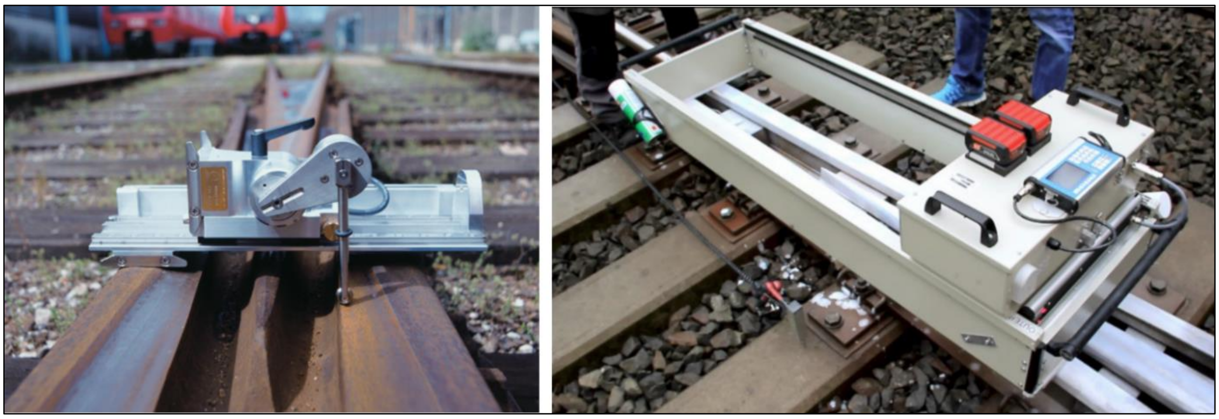

Fig. 4 – The measurement systems "MiniProf" (left) and "Scorpion" (right) (pictures: [10, 11])

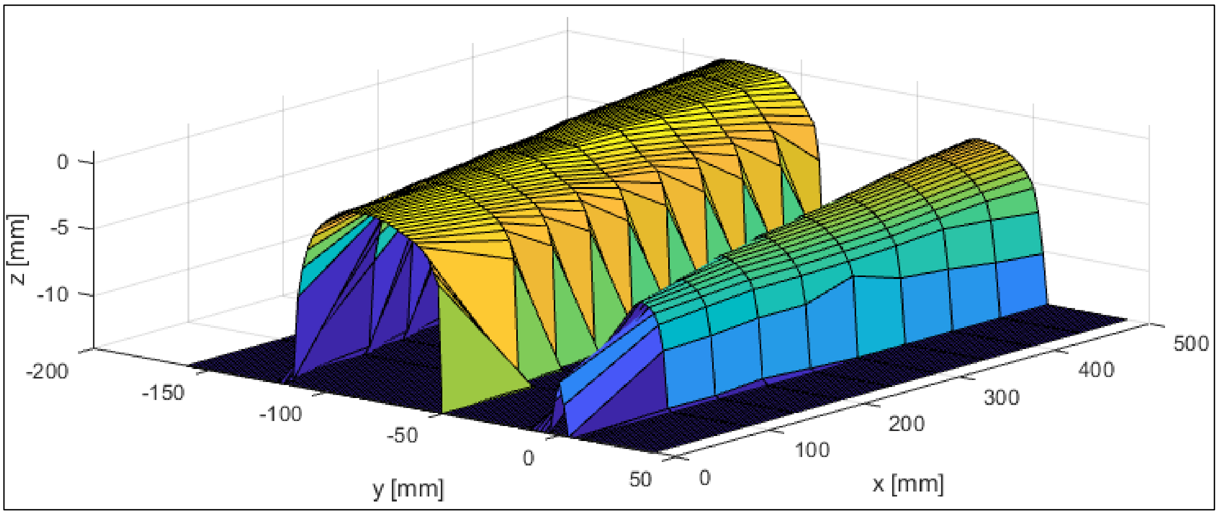

Fig. 5 – Example for a measured 3-D-model of frog and wing rail running surfaces[5]

4. Design of a Method for Geometry Optimization of Switch Frogs

In the course of 15 years of operation of the test track, almost 100 switch frog samples with different properties have been subject to geometric (MiniProf, Scorpion) and inertial (ESAH-M) measurements throughout their lifetimes. To minimize the dimensions of the problem, 13 switch frogs of the same material, switch radius and direction of travel[6] have been selected as a database for the first optimisation approach. In order to detect the decisive geometric parameters for a prolongation of the switch frog lifetime, the measurement data have to be correlated with the observed degradation processes of the switch frogs. Therefore, the state of the running surfaces of the examined switch frogs has been protocolled and evaluated by experts at each time of measurement.

However, establishing a connection between the measured geometric and acceleration data on one hand, and the progress of the running surface degradation on the other hand, has proven to be a challenging task. Although, nowadays, methods for intelligent data analysis ("data mining") are at hand, no ensured correlation has been found yet in this project.

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[5] As switch frogs at the test track are used in the straight direction only (cf. *fig. 2*), only the corresponding (left) wing rail is visualised.

[6] Steel quality: R350HT; switch radius: 500 m; direction of travel: facing move

The reason for the difficulties can be detected by examining the causalities in the geometry-dependent deterioration process (*fig. 6*): According to the switch frog geometry, that always includes discontinuities in the passage, accelerations are imposed on rails and wheels. Depending on the stiffness properties of the track and substructure, those accelerations are the cause for dynamic wheel forces. These forces, again in the interaction of rail and wheel geometry, evoke the formation of an ellipsoidal contact area and a corresponding contact pressure. This contact pressure can be seen as the direct cause of the switch frog running surface deterioration.

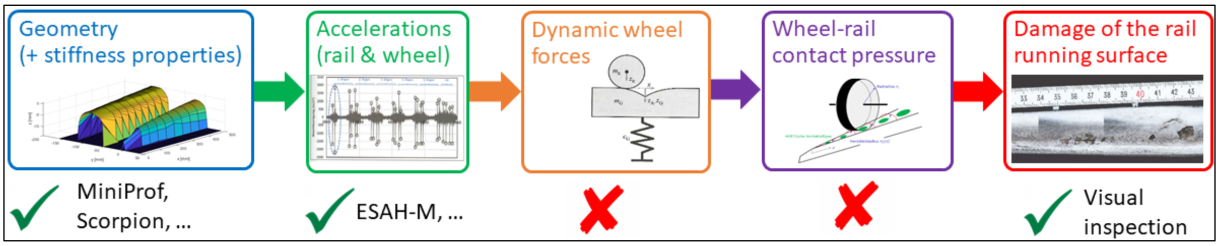

Fig. 6 – Causalities and available measurement systems in the process of running surface degradation

At the bottom of figure 6, the measurement systems used at the test track are associated with the corresponding stage in the causality chain. At the two central stages (wheel forces and wheel-rail contact pressures), no devices for conducting large-scale measurements are available. Therefore, at the attempt of using statistical methods for correlating the measurement data, a large scattering of the data points and a relatively vague correlation of the examined parameters is to be expected.

As an approach to the problem, it is envisaged to fill the gap in the causality chain using simple calculation models. For this purpose, three separate models have to be developed (orange, violet and red arrows in fig. 6), where the interim results of the models cannot be matched to measurement data. Therefore, plausible assumptions have to be made (e. g. as proposed in [9], [1], [11]) in order to reduce the number of free model parameters to a possible minimum. The remaining model parameters can then be fit to match the measured data, which serve as input and output data of the model chain respectively.

By this means, a connection between switch frog geometry on one hand and the damage of the switch frog running surface on the other hand can be established. Vast volumes of data, as well as experts' experience obtained at the test track near Hannover can be moulded into one algorithm. At the same time, the modelled part of the algorithm provides a guideline through causal relationships in the process of switch frog running surface deterioration.

5. Conclusions

This paper has presented an approach, how the vast data material acquired at the German Railways' test track can be used to correlate geometric parameters of switch frogs with the damage of their running surface. As the causal relation between the two dimensions is evident, but distant, purely statistical approaches are not apt to solve the problem. Therefore, it is proposed to use simple calculation models to outline the causality in the deterioration process. The success of the proposed method still remains to be seen in the future of the running investigation project.

Once the full calculation algorithm has been established, it can be used to identify those geometric parameters responsible for the observed variation in switch frog lifetimes. Optimization algorithms can then be applied to find an optimal switch frog geometry for the examined case of loading.

As the underlying case of loading (isolated switch frogs installed at the test track) is still far from real-world conditions, the developed model will have to be extended gradually to cover, above all, different directions of travel and passages in the divergent track. Furthermore, varying model parameters for different materials can be obtained by changing the underlying database.

Eventually, the developed model, aligned with the abundant data material collected over years, will serve as a tool to illuminate several aspects of the process of deterioration on the running surfaces of switch frogs. A significant advance in the construction and assessment of rigid switch frogs will finally also be reflected in the form of economic benefits.

Acknowledgment

This work was supported by the Grant No. 22120015. The project is co-financed by the Governments of Czechia, Hungary, Poland and Slovakia through Visegrad Grants from International Visegrad Fund. The mission of the fund is to advance ideas for sustainable regional cooperation in Central Europe.

supported by
Visegrad Fund

References

[1] GERBER, U. – FENGLER, W. (2007): Belastung von Weichen mit starrer Herzstückspitze [*load of switches with rigid frogs*], in: ZEVRail - Glasers Annalen, issue 131, p. 202 – 214

[2] GERBER, U. – ZOLL, A. – FENGLER, W. (2015): Verschleiß und Fahrflächenermüdung an Weichen mit starrer Herzstückspitze [*Wear and Contact Fatigue in Switches with Rigid Frogs*], in: Eisenbahntechnische Rundschau (ETR), issue 2015, No. 1+2, p. 36-41

[3] LAY, E. – RENSING, R. (2013): Weichen [*Switches*]. In: Fendrich, L./ Fengler, W. (Hg.): Handbuch Eisenbahninfrastruktur [*Compendium of Railway Infrastructure*], Berlin: Springer, p. 239-306

[4] ZOLL, A.: Werkstoffauswahl für Weichenherzstücke durch Prüfstandversuche [*Materials Selection for Switch Frogs using Test Bench Trials*]. Dissertation, Technische Universität Berlin [*Technical University of Berlin*]. Aachen: Shaker; 2016.

[5] ZOLL, A. (2005): IAW – Instandhaltungsarme Weichenfahrbahn [*Low-maintenance Switch*], in: Bundesministerium für Bildung und Forschung (BMBF) [*Federal Ministry of Education and Research*] (ed.): Innovation für die Schiene, Bahnforschungsprojekte des BMBF [Innovation for the Track, Railway Research Projects of the BMBF], Bonn/Berlin: BMBF, p. 80-82 (downloaded 13.06.2019, 10:00 am: http://d-nb.info/978298551/34)

[6] Nielsen, J. – Ekh, M. – Kassa, E. – Iwnicki, S. – Nicklisch, D. – Grönlund, W.: Optimisation of Switches and Crossings. In: Ekberg, A. (Hrsg.) – Paulsson, B. (Hrsg.): INNOTRACK – Concluding Technical Report. International Union of Railways (UIC), 2010, S. 161 – 167

[7] KLUGE, F. (2020): Wege und Irrwege der Herzstückforschung [*Leading and Misleading Tracks of Switch Frog Research],* in: Eisenbahn-Ingenieur-Kompendium (EIK), issue 2021, p. 323 - 334

[8] ZOLL, A. (2018): ESAH-Diagnosetechnik: Elektronische System-Analyse im Herzstückbereich [*ESAH Diagnostic Technology: Electronic System Analysis in the Frog Area*], Brandenburg-Kirchmöser: DB Systemtechnik GmbH (downloaded 13.06.2019 10:00 am: https://www.db-systemtechnik.de/resource/blob/3233610/763f3cb992 a3cf3ab0fbdf6dfe21a18f/Aktuell_weichenherzstueckdiagnose_esah_deutsch-data.pdf)

[9] GERBER, U. – FENGLER, W. – ZOLL, A. (2015): Das Messsystem ESAH-M [*The measurement System ESAH-M],* in: Eisenbahn-Ingenieur-Kalender (EIK), issue 2016, p. 49 - 62

[10] Greenwood Engineering A/S (2019): MiniProf Rail Product Information (downloaded 19.06.2019 1:00 pm: ftp://ftp.greenwood.dk/miniprof/pdf/MiniProf-Rail.pdf)

[11] JIANG, D. (2019): Ein Beitrag zur Ermittlung der Nutzungsdauer von Weichenherzstücken [*A contribution to determine the service life of the turnout frogs*], Diss., TU Dresden [*Technical University of Dresden*], Dresden