Railway switch design optimisation using a kinematics-driven approach

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EXTENDED ABSTRACT

1 Introduction

Switches and crossings rank among the top priorities of railway infrastructure managers due to their high installation and maintenance costs. The quest for increases in speed and higher loads motivates the investigation of how to optimise the switch geometries to minimise wear while guaranteeing safety standards are met. The majority of the existing optimisation approaches depend on the intensive use of dynamics simulations, that are expensive from the computational point of view, to assess the effect of certain design parameters on wear, rolling contact fatigue (RCF), and the vehicle behaviour.

Pålsson [1] performs a multi-objective optimisation of geometric parameters using a genetic algorithm with the aim of minimising the contact pressure (associated with RCF) and energy dissipation (associated with wear). The switch rail profile designs are evaluated inside the optimisation algorithm using dynamic simulations. The optimised switch rail geometries are further evaluated using dynamic simulations and using 120 measured wheel profiles.

Nielsen et al [2] compare two models to predict wear and RCF for the design of a switch rail. Different designs with varying switch rail height and rail inclination are compared using dynamic simulations. The study stresses the importance of accounting for the variability of the traffic type, friction coefficient at the wheel-rail contact, vehicle speed, and worn wheel profiles.

In a previous study [3], Pålsson and Nielsen describe how a local increase in the track gauge can minimise the perturbation caused by the asymmetry between the stock and switch rail profiles. A genetic algorithm is used to optimise the track gauge increase, considering variability in the wheel profile, friction coefficient, and routes and directions of travel. The results show that it is possible to reduce the energy dissipation that is associated with wear.

This work proposes an alternative methodology that prioritises the study of the kinematics of the wheelset-switch interaction to minimise wear and RCF while also guaranteeing adequate levels of vehicle performance. The analysis presently focuses on the facing-through direction and disregards the negative effects of the design changes on the other travel directions.

2 Kinematics of wheelset-switch contact: the rolling radius difference (RRD) function

One relevant quantity used to describe the insertion of the wheelset on the track is the rolling radius difference function, RRD(y) = R1(y)-R2(y), which depends on the lateral displacement y and the rolling radius of the wheels, depicted in Fig. 1. The RRD function describes the steering of the wheelset on the track and the hunting motion when the wheelset is subjected to an external perturbation. In a straight track without irregularities the RRD function is smooth and anti-symmetric. On the contrary, in the case of a switch panel, the RRD function also depends on the travelled distance x, and is non-smooth and asymmetric. In particular, in the through route, the negative values of the RRD function for small lateral displacements y steer the wheelset toward the switch rail, leading to flange contact between the wheel and the switch rail while the wheel moves from the stock rail to the switch rail.

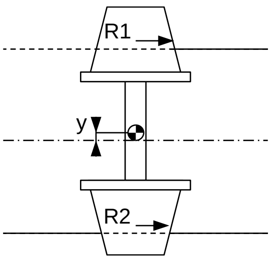

Figure 1: Schematic representation of a wheelset, showing the lateral displacement y relative to the track centreline, and the rolling radius of the wheels, R1 and R2.

3 Optimisation of switch geometry

Figure 2 graphically illustrates the optimisation procedure proposed in this work. A library of previous simulations of the vehicle-switch interaction allows improving the knowledge concerning the mechanisms that explain the kinematics of the wheelsets when traversing the switch. This includes the analysis of the lateral displacement of the wheelset and the positions of the points of contact as a function of the travelled distance. The same library of previous simulations provides useful knowledge on the dynamics of the vehicle-switch interaction, mainly concerned with the forces developed, as well as the energy dissipated by friction, and the contact pressures, that can be associated with regular wear and RCF. A library of switch geometries and a library of wheel profiles are also required for the optimisation procedure.

The rationale behind the proposed approach is the assumption that wear is minimised if the geometry of the switch rail is optimised considering the range of wheel profiles that travel over the switch panel. In analogy to the work by Shevtsov et al [4], switch designs are the result of an optimisation procedure to achieve a target RRD function.

A large collection of RRD functions is computed by associating a selected switch geometry with different pairs of left and right worn wheel profiles. The different RRD functions are combined to define a simple average, or a weighted average that better describes the variability of wheel profiles in a given railway section. The averaged RRD function is pre-emptively considered the optimum RRD, and defines the target RRD. The optimisation procedure involves using a meta-heuristic method to determine the switch geometry, described by a set of design variables, whose RRD better matches the target RRD, by minimising the difference function and using a single pair of wheel profiles. A minimal set of dynamic simulations is run using the new switch geometry to obtain the quantities that describe the contact kinematics and dynamics and allow comparison with the original switch geometry.

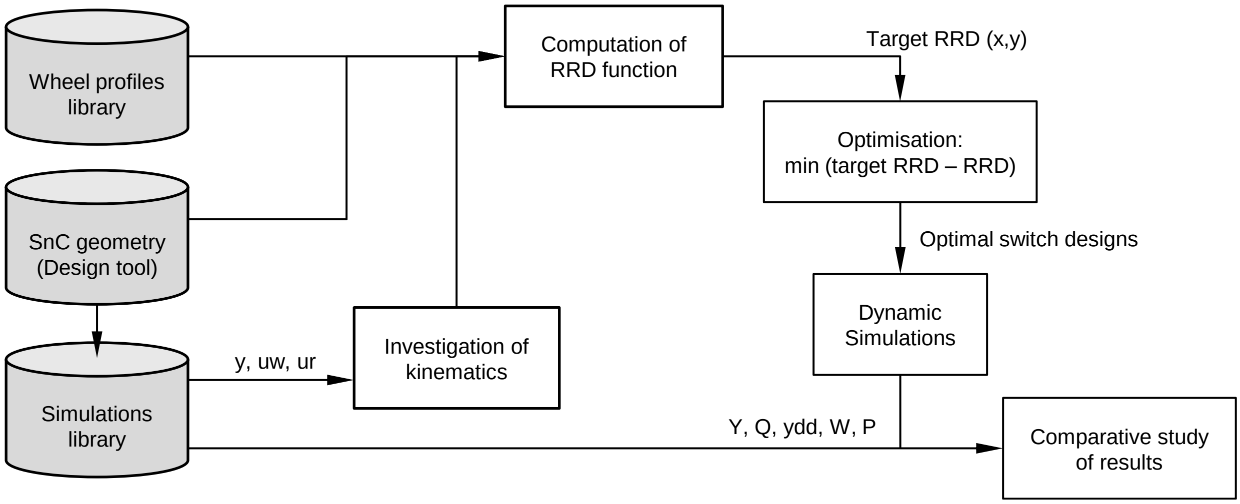

Figure 2: Overview of the proposed design sequence.

4 Conclusions

This work provides an alternative approach to the design of railway switches that prioritises the analysis of the kinematics of the wheel-switch contact in the facing-through direction. The RRD function is the focus of the optimisation procedure and supports the description of how the wheelset negotiates the switch. This approach is intended to minimise the use of dynamic simulations in the optimisation process and its associated computational cost. Nonetheless, the new switch designs are compared with existing designs using a minimal set of dynamic simulations. This comparative analysis focuses on the quantities associated with vehicle stability, comfort, wear, and RCF.

Acknowledgments

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