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Investigating the Impact of Foreign Objects on Railway Switch Control: Numerical Simulations and Field Measurements

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Abstract

Railway switches enhance the flexibility of railway networks, yet they frequently contribute to operational disruptions. Disruptions often arise from foreign objects trapped between stock rail and switch rail. This cause delays resulting in elevated costs. This research assesses the influence of such foreign objects on the control of the switch rails, potentially preventing the switch from locking or causing gauge narrowing, thus increasing the risks of derailment. To this end, a finite element model of a UIC60-760-1:15 switch has been developed and validated against field measurements. The findings reveal that friction between the switch rail and slide chairs plays a crucial role in control of the switch rail in the presence of a foreign object. Hence, it becomes necessary to carry out maintenance on switches regularly and design systems to prevent interference of trapped foreign objects in operation.

Keywords: switch and crossings, foreign object, finite element simulation, field measurements, condition monitoring, multi body dynamics.

1 Introduction

Switches and crossings (S&Cs) are crucial for railway operations, offering the flexibility needed to direct trains along various routes [1, 2]. The reliability of these switches significantly impacts the overall efficiency of the rail network [3,4].

One common form of disruption to switch operations is when foreign objects get trapped between switch rail and stock rail. This may prevent the switch from being in control and thus will block traffic [5, 6]. By being in control, it is meant that the drives and any additional sensors report to the signalling system that the switch rail is positioned within tolerances and that traffic can pass.

S&Cs and TKKs stand for large portions of maintenance budgets [6]. In addition, failure, or disturbances of S&Cs and TKKs cause indirect costs in the form of traffic disruptions [1, 13]. Figures from Trafikverket in 2017 show that the TKKs indicated 350 errors, of which only 5 were correctly indicated errors (1.5%) [7]. These false errors resulted in at least 1021 delayed trains in 2017 with 257 delay hours [5], exerting the importance of developing more reliable and robust design for switch monitoring and control.

An outline of a standard Swedish railway switch panel is shown in Fig. 1. The switching function is realised by drives (point machines). The drives position the switch rail either in the through (green rails) or diverging route (blue rails). In the studied switch, each driver exerts a nominal force of up to 6 kN to actuate the switch rail [7, 8]. In Sweden the gap between switch and stock rail is actively monitored by using a position sensor called TKK (indicated by purple colour) and seen in Fig. 1. TKK is a Swedish abbreviation for 'switch rail control contact' [6, 9, 10]. In the considered switch panel, gaps are monitored at four separate locations by TKK sensors, can be seen in Fig. 1.

At three locations, the left and right switch rails are connected together by links, which are long cylindrical bars as seen with pivoting bolt connections as seen in Fig. 1. The main purpose of the links is not only to increase the bending stiffness of the switch rails by connecting them in parallel, but to ensure that the distance between the switch rails remains fixed. The switch rails are supported on a sleeper mounted slide chair and rollers to enable smooth operation.

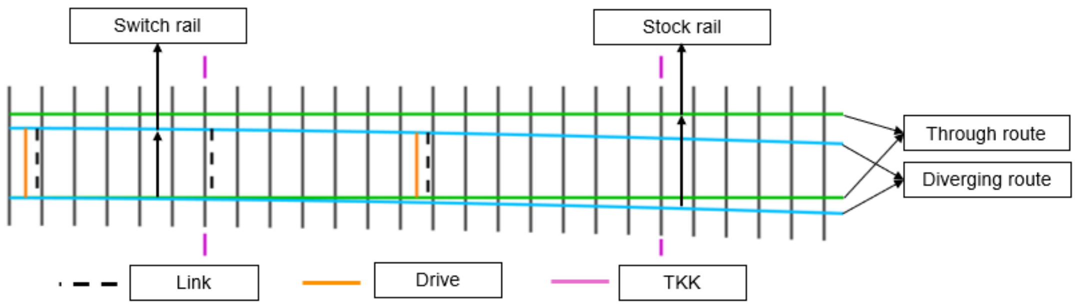


Figure 1. Schematic top view of the studied switch panel.

According to the Swedish regulations [8], a drive is in control if the gap between the switch and stock rail at the drive is less than the tolerance limit of 3 to 5 mm. During inspections, the drive must be in control for a 3 mm gap and not be in control for a 5 mm gap. As it is possible for the switch to be in control for any gap arbitrarily close to 5 mm, the upper tolerance limit of 5 mm is considered to determine control of the drive for this study.

Similarly, for the TKK to be in control, the gap between the switch and stock rail at the position of the TKK should be less than 10 – 13 mm [8]. For this study, the upper tolerance limit of 13 mm is considered. The TKK is installed in addition to the drives to detect excessive gauge narrowing. In general, a rail gauge reduction of 15 mm could lead to hard flange contact but should not pose a risk of derailment under nominal conditions [12].

This introduction highlights the need for monitoring switch rail control to ensure the safe operation of trains. It acknowledges, however, that such measures can generate erroneous fault signals, leading to unnecessary disruptions. Additionally, it notes that while switch and drive monitoring has been explored, there are no published studies on the impact of foreign objects on switch operations.

The objectives of this study are therefore to develop a simulation capability to examine the influence of foreign objects and to validate the simulation model against field measurements. To achieve this, a finite element (FE) model of a UIC60-760-1:15 switch panel, including both switch rails and their connecting links, has been constructed. This model has been validated with field measurements involving interfering objects at two switches. The study also investigates the effect of friction between switch rail and slide chair on switching operations.

2 Simulation model

The finite element (FE) model is constructed in ABAQUS [14] and includes both the switch rails and their connecting links, as seen in Fig. 2. In this model, only the portions of the stock rail that may be in contact with the switch rail are included, referred to as stock rail support structures. These support structures are modelled as fully constrained rigid bodies. The rear ends of the switch rails are constrained in all directions to prevent rigid body motion. To minimize computational effort, the sleeper-mounted slide chair supports beneath the switch rail are modelled as continuous rigid plates, constrained in all degrees of freedom, as shown in Fig. 2.

Contacts between the switch rail, stock rail support structures, and slide chair are defined with a constant friction coefficient throughout a simulation step. The

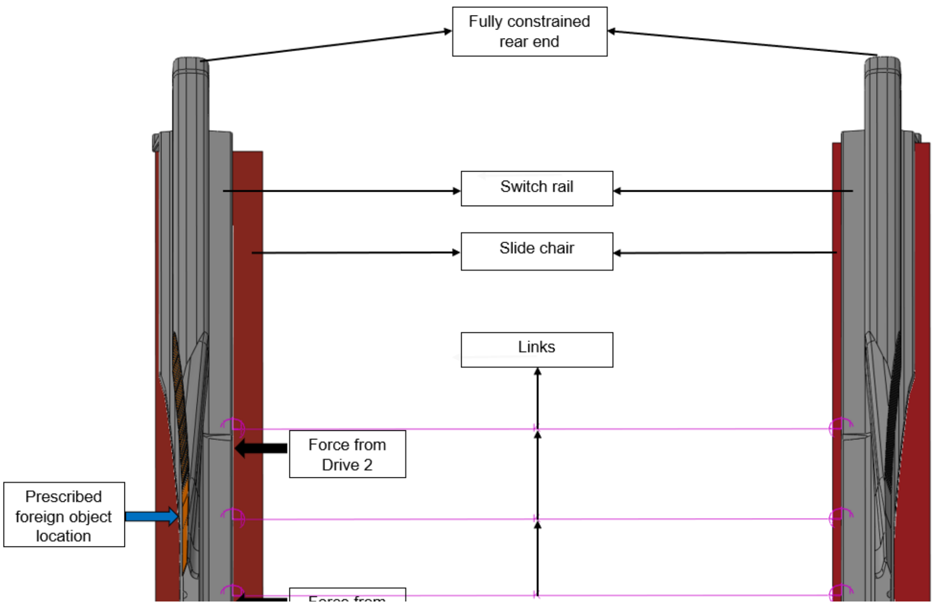


Figure 2. FE model of the simulated switch rails with three connecting links [4].

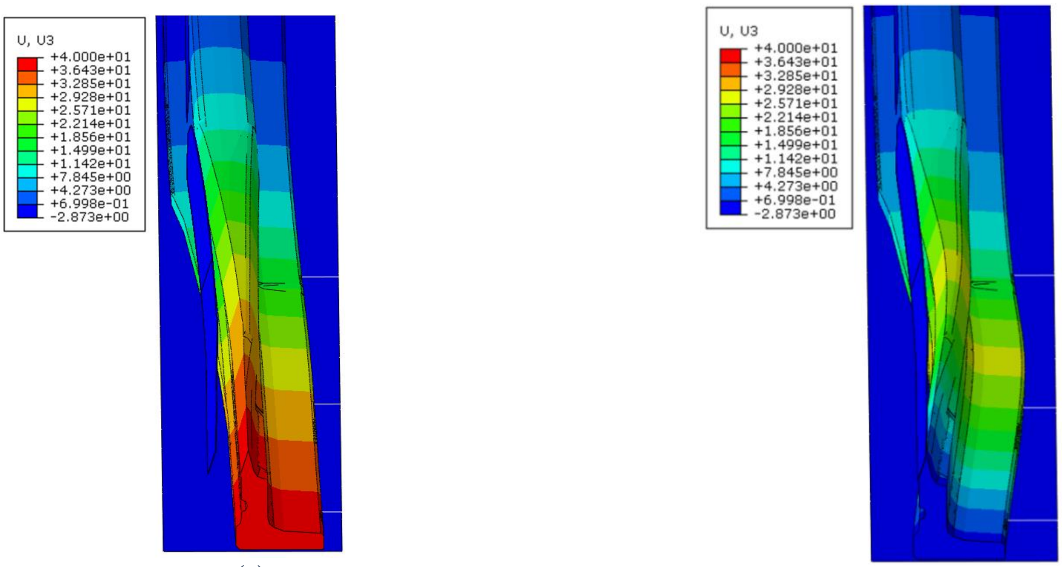
connecting links are simplified into linear springs with a stiffness of 1.5 kN/mm to reduce computational resources.

Switch rail steel is modelled with a Young's modulus of E = 210 GPa, Poisson's ratio of ν = 0.3, and a density of ρ =7 850 kg/m3. The switch rails are discretized by solid tetrahedral elements (C3D4) of the first order. The switch model consists of around 535 000 elements and 140 000 nodes. Rigid support structures (stock rail and slide chair) are made up of 4 noded rigid 3D quadrilateral elements (R3D4). In total the FE model consists of 1 064 106 degrees of freedom.

The drive forces are modelled as point forces acting in the lateral direction, which push and hold the switch rail against the stock rail. Individual drives are designed to exert a force of 6 kN.

The trapped foreign object is modelled as a prescribed lateral displacement at the foot of the switch rail, which can be positioned at various locations between the drives. The simulation process comprises two steps corresponding to the opening and closing of the switch.

In the first step, the switch is opened by a prescribed displacement equal to the size of the foreign object, with no drive forces acting. The friction coefficient in this step is set to 0.1 to allow the switch rail to deform outward with minimal resistance. This results in a widening between the switch and stock rail, as shown in Fig. 3a. To simplify modelling and reduce simulation time, the switch is only opened enough to accommodate the object, rather than simulating the full range of lateral movement in switch operations. In the second step, corresponding to the closing of the switch, the drive forces are activated to push the switch rail against the stock rail. Due to the presence of the foreign object, a residual gauge narrowing occurs, corresponding to the size and location of the object, as illustrated in Fig. 3b. In this step, the friction coefficient is varied to examine its impact on the lateral displacement along the switch



(a) (b)

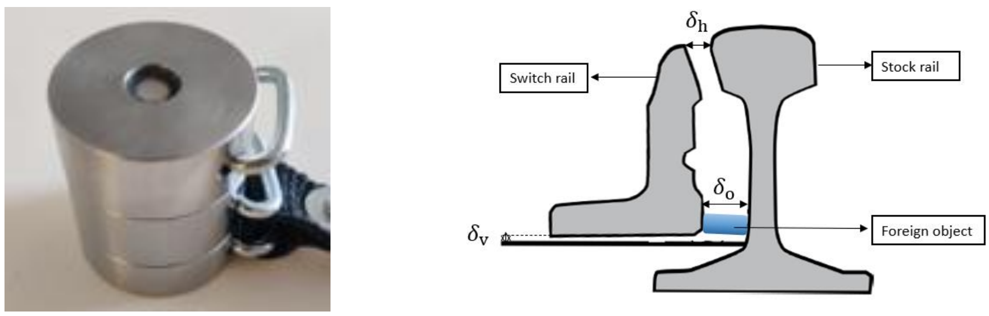
Figure 3. Lateral deformation field (U3 [mm]) in the switch rail after (a) Simulation step 1: introduction of foreign object, (b) Simulation step 2: application of drive forces [4].

rail. Further details of this investigation are provided in subsequent sections.

2. Measurements in field

Field measurements were conducted on a UIC60-760-1:15 S&C in Vätteryd, Sweden, in September 2022. The S&C in the tests will be referred to as 'Switch-A' from here on and was situated on an operational railway line.

The objective of the test was to gather data on switch rail deformations caused by foreign objects, which would be used to validate the FE model. The test setup is illustrated in Fig. 4. During the tests, the switch was opened, the foreign object was placed in position, and then the switch was closed to observe the deformed shape with the foreign object in place.



(a) *(b)*

Figure 4. Setup for field measurements. (a) Aluminium spacer with magnets used in the tests. Size of the spacer is 36 mm (b) Cross-section of test setup where the foreign object is placed on the web just above the foot of the stock rail. Horizontal (δ_h) and vertical (δ_v) gaps between the switch and stock rail. δ_0 is the size of the foreign object [4].

An aluminum spacer equipped with a magnet for fastening (see Fig. 4a) was used to simulate a foreign object. The spacer was placed between the foot of the switch rail and the web of the stock rail, as shown in Fig. 4b. This location was selected because it is considered the most likely spot for an interfering object to be positioned.

The initial horizontal gap (without the foreign object) between the web of the stock rail and the foot of the switch rail is between 6 mm for Switch-A. Consequently, the effective object size (δ_{E0}) and the resulting lateral gap (δ_h) at the top between the switch and stock rail becomes 30 mm for a 36 mm object.

The distance between the drives in the switch is 7270 mm. Normalized position (w.r.t distance) 0.45 in Fig.5, corresponds to sleeper 7 in the switch panel. The TKK is located at the middle position (sleeper 7). Drive 1 is located between sleeper 1 and 2 and the second drive is located between sleeper 13 and 14.

In the tests, horizontal (δ_h) and vertical (δ_v) gaps between the switch rail and stock rail, as well as between the switch rail and slide chairs, were measured at the cross-sectional positions indicated in Fig. 4b. Measurements were taken at the five

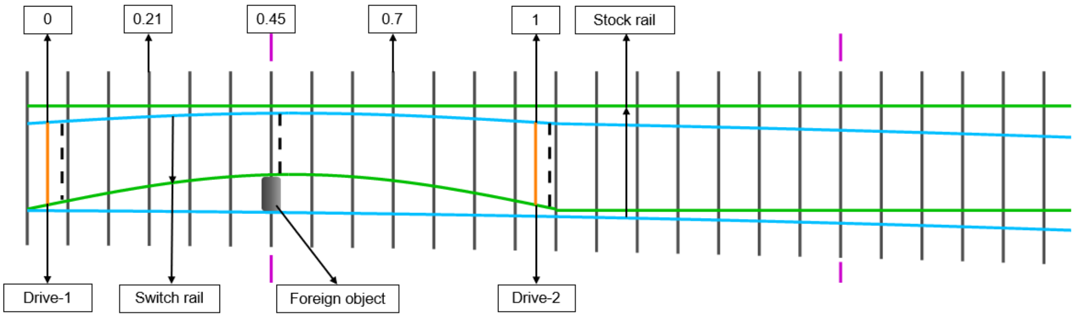


Figure 5. Longitudinal positions between the drives where measurements are taken in the tests. Positions along the switch rail are normalized against total distance between the drives. Positions 0 and 1, refer to drive 1 and drive 2 respectively. Purple lines indicate TKK positions.

longitudinal positions shown in Fig. 5, including the object and drive locations. The vertical gap (δ_v) was measured using blade gauges, while the horizontal gap (δ_h) was measured with Vernier callipers. These measurements were taken both before and after the introduction of the foreign object.

Without the object, the rails were either in contact or very close to each other (with less than a mm deviation) along the length between the drives. The vertical gaps exhibited slightly more variation but were within a few mm, with no significant changes observed whether the object was present or not. Therefore, no notable twist of the switch rail was detected when the object was introduced.

Test number	δ_0(mm)	Drive 1	Drive 2
1	36	NOT	NOT
2	36	IN	NOT
3	36	IN	IN

Table 1. Condition of drives in Switch-A during tests with foreign object placed at 0.45 position. 'IN' indicates drives in control and 'NOT' not in control.

The resulting lateral displacements for the object placed at 0.45 positions is shown in Fig. 6. The lateral displacements in the region near drive 1 are lower than at drive 2 because the cross-section near drive 1 is thinner and the tip of the switch rail is free. This allows the drive to close the gaps more effectively. During the test in switch A, it was observed that the final drive control status varied for successive tests as presented in Table 1. This could be because the drives in the first test have been inactive and may be cold (ambient temperature around 5 C). Thus, they may not be able to exert the force required to close the switch. With successive runs, the drives after going through a number of heat cycles are able to exert the maximum force, which results in control of both drives. The results seem to indicate a rather pronounced sensitivity to the drive conditions.

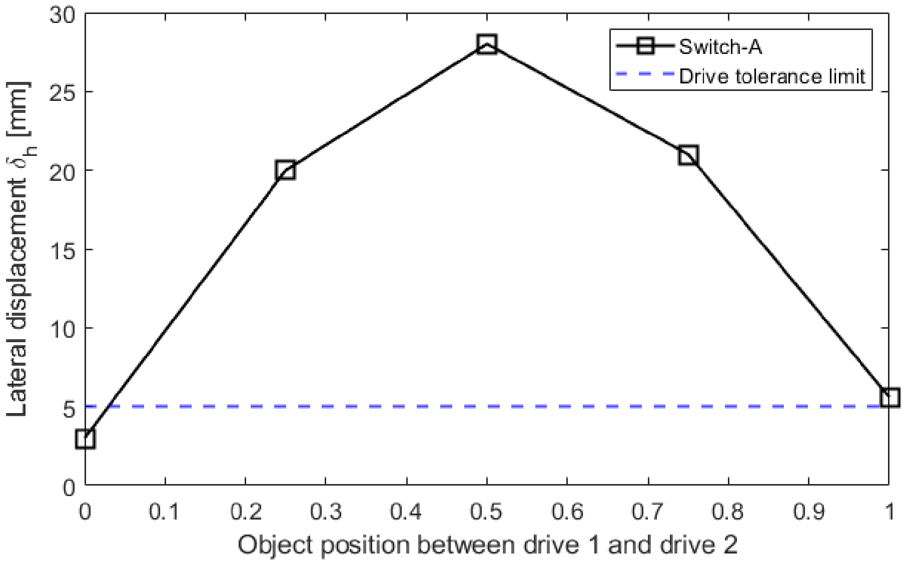


Figure 6. Measured lateral displacements from tests conducted on switch A, for varying object position along switch rail between drive 1 and drive 2.

4. FE model calibration and sensitivity

The main aim of this section is to calibrate the FE model to field measurements and to investigate the reasons behind the deviation of the results. This is done by investigating the influence of friction coefficient for the values 0.1, 0.4 and 0.7. Field measurements and results from FE simulations with different friction coefficients are compared and plotted in Fig. 7. The comparisons show that the FE simulations are able to capture the deformation pattern well. FE results and field measurements are in good agreement, with maximum deviations on the order of 1 to 3 mm. Indeed, there is a significant influence of the friction coefficient on the final deformation pattern as it affects the final control condition of the drives. For example, in the case when the object is placed at position 0.45, drive 2 is in control when the friction coefficient is 0.1, but goes out of control when it is increased to 0.4 and 0.7.

Lateral displacements at drive 1 are unaffected. This is because the free end of the switch rail comes into hard contact with the stock rail for all frictional levels and the friction forces are not large enough to affect the displacement at this location.

Lateral displacements at drive 2 on the other hand are non-linearly affected by friction. In reality a well-maintained switch has a low friction coefficient and hence would be able to cover the gap at the drives. Failure to maintain the switch properly, leading to increased friction, may cause significant lateral displacements near drive 2. Consequently, this could give a reading of excessive gauge widening for the TKKs situated behind drive 2 even though no object is interfering. Overall, the model is effective in capturing the non-linearity in lateral displacements of the switch rail for different initial conditions and loading.

Based on this comparison, it can be concluded that the FE model is validated and

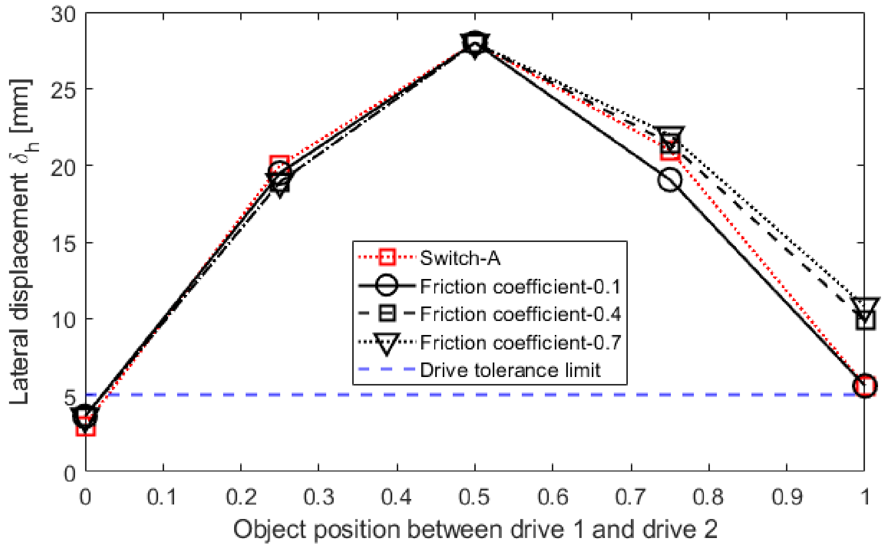


Figure 7. Comparison between field measurements and results from FE simulations for different friction coefficients regarding lateral displacements after the second simulation step

friction coefficient of 0.1 gives the best fit with respect to the field measurements. This indicates that the switches were lubricated, and that the roller supports for the switch rail were working properly.

Concluding remarks and future work

Field measurements were carried out on railway switches to study the influence of trapped foreign objects on switch operations. During the measurements, lateral displacements between switch and stock rail and status of drives were recorded. Comparison of results between the FE and field measurements showed a very good agreement. This means that the FE model can estimate the influence of foreign objects and will be beneficial in developing switch systems with improved control tolerances. It will also reduce the need for additional physical tests. The validated FE model can be extended to perform a parametric study on the influence of position and magnitude of foreign object on switch rail control. The study will give an idea about the efficiency and drawbacks of the already implemented switch systems and will provide scope for improvement of these systems.

Future studies will focus on whether switch design and instrumentation can be improved to make it more robust and therefore less sensitive to, e.g. excessive friction. Further, it is of interest to investigate what the actual consequences would be in situations of gauge narrowing as long as the drives are in control (but not the TKKs).

Preliminary studies show that ballast stones will be crushed by the passing train load if trapped between switch and stock rail at the TKK location [15].

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