Identification of Trapped Foreign Objects in Railway Switches Using Drive Outputs

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ABSTRACT

Railway switches are crucial in enhancing railway network flexibility but are also a significant source of operational disruptions. A common cause of disruption is when foreign objects such as ballast stones, metal debris, snow, or ice become trapped between the switch and stock rail during switch rail actuations. Such obstructions can hinder switch operations and thereby cause train delays and increased operational costs. If they cause significant local gauge narrowing, there is an increased risk of derailment if trains pass by. To prevent such scenarios, it is crucial to accurately and cost-effectively identify trapped foreign objects at an early stage. The Swedish switch designs currently in operation often use a combination of drive (point machine) locking tolerances and additional position sensors along the switch rail to detect foreign objects that can constitute a derailment risk. These sensors require maintenance and sometimes cause traffic disruptions by themselves due to malfunction.

When an obstruction is present, the drive exerts additional force to close the induced gap via bending of the switch rail, resulting in increased power and current consumption. The aim is to develop a robust condition monitoring system for identifying trapped foreign objects by analysing the current output of drives in addition to their locking tolerances. By examining current output curves, deviations from ideal operational conditions can be observed, enabling the identification of dangerous objects.

The aim of this paper is to analyse deviations from ideal operational conditions for different object scenarios by utilizing a multibody simulation (MBS) model of a standard switch. Simulations were carried out for varying object sizes and positions between the drives. The presence of a trapped foreign object under various operational conditions was detected by analyzing the force-displacement outputs at the drives.

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INTRODUCTION

Switches and crossings (S&Cs) play an integral role in providing flexibility to the complex railway network by allowing trains to change from one track to another [1,2]. But this flexibility comes at a cost as S&C, and especially the switch with moving parts, are prone to failures that cause traffic disruptions and require significant maintenance. Hence, unreliable switch performance will impact the functioning of the entire railway network. A common disruption in switch operations occurs when foreign objects—such as ballast stones, metal debris, or snow and ice—become lodged between the switch rail and stock rail during actuation. Data from Trafikverket (The Swedish Transport Administration) which analyzed railway infrastructure faults for the year 2017, showed that about 14% (1188 out of 8597) of the total faults were due to trapped foreign objects in the switch. Detailed description about fault classification can be found in [3, 4].

In a standard Swedish S&C, the job of identifying trapped foreign objects is performed by a combination of drives (point machines) and a displacement sensor called TKK (switch rail control contact), which can be seen in Figure 1 (details about the switch design can be found in [3,4]). There are two pairs of TKKs that measure the gap between the switch and stock rail and alert if the gap is 13 mm or more [5, 6]. Actuation of the switch rail between the through (green) and diverging tracks (blue) are carried out by two drives that each exert a maximum force of 6 kN [6, 7]. Drives are in control if the gap between the switch and stock rail at the drive is 3 mm or less [6]. The challenge with locking detection at drives and TKKs, is their reliability. They can sometimes falsely indicate faults, which can result in unnecessary traffic disruptions. Further, additional sensors such as TKKs add cost and maintenance demands. It is therefore of interest to investigate if object detection can be performed reliably using only information from the drives. In this paper, the aim is to investigate this by developing a robust condition monitoring system for identifying trapped foreign objects by analysing the current output of drives in relation to their locking tolerances.

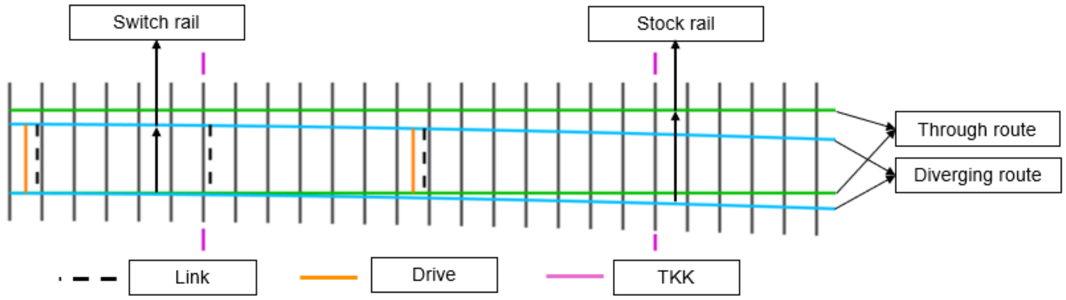

Figure 1. Overview of a standard Swedish S&C.

STATE OF THE ART

Previous research has demonstrated that analyzing drive outputs through various condition monitoring approaches can successfully detect faults, anomalies, and component failures [8–13]. These techniques have leveraged a range of methods including machine learning, artificial intelligence, and, in some instances, image and sound analysis to monitor the health of drives. The implemented methodologies were effective in detecting the specific faults for which they were designed, thereby validating their potential in real-world applications.

Building on this established foundation, this paper seeks to extend the application of these techniques to the detection of trapped foreign objects in railway switches. The proposed approach involves the adaptation of existing fault detection methodologies to identify subtle variations in drive outputs that are indicative of foreign object presence. The algorithms would be trained to recognize patterns and deviations from normal operation, even when the foreign object is small or its influence on the signal is minimal. This will be reflected in current, or power outputs as the drive would exert additional force to close the induced gap via bending of the switch rail.

This paper focuses on conducting multibody simulations (MBS) under varying foreign object conditions to evaluate their impact on drive forces. The resulting data will serve as a foundation for training a condition monitoring system. The ultimate aim is to develop a robust, real-time detection method that can be integrated into existing systems to reduce downtime, lower maintenance costs, and improve overall railway safety.

MULTIBODY MODEL

Multibody simulations of the switching operation were carried out in Simpack [14]. Rails are modelled as flexible bodies from Timoshenko beam elements using the non-linear flextrack module in Simpack. The varying properties of the switch rails due to their tapered ends are accounted for. This implies reduced mass and bending stiffness towards the rail ends [15]. All rails are condensed into super elements using a Craig-Bampton reduction [16]. Sleepers are omitted to reduce computational demands, given the quasi-static nature of the switching operation as dynamic wheel loads are excluded. A detailed explanation of the switch modeling used in this study is provided in [3]. The topology of the MBS model used can be seen in Figure 2.

The model includes three links that connect the through and diverging switch rails, that are modelled as linear springs of 1.5 kN/mm stiffness. The link lengths vary with position in the switch. They are shorter towards drive 1 where the switch rails are closer to one-another and thus the stroke required to shift the switch position is longer. The switch is actuated by two drives that are modelled using prescribed displacements and corresponding forces and displacements at the drives are measured. The foreign object is modelled as a bi-linear spring with a linear stiffness of 40 kN/mm when engaged and 0 otherwise. Influence of the foreign object position between the drives is investigated in the RESULTS section. As the foreign object is located towards any of the two drives the probability of it being detected increases significantly [4].

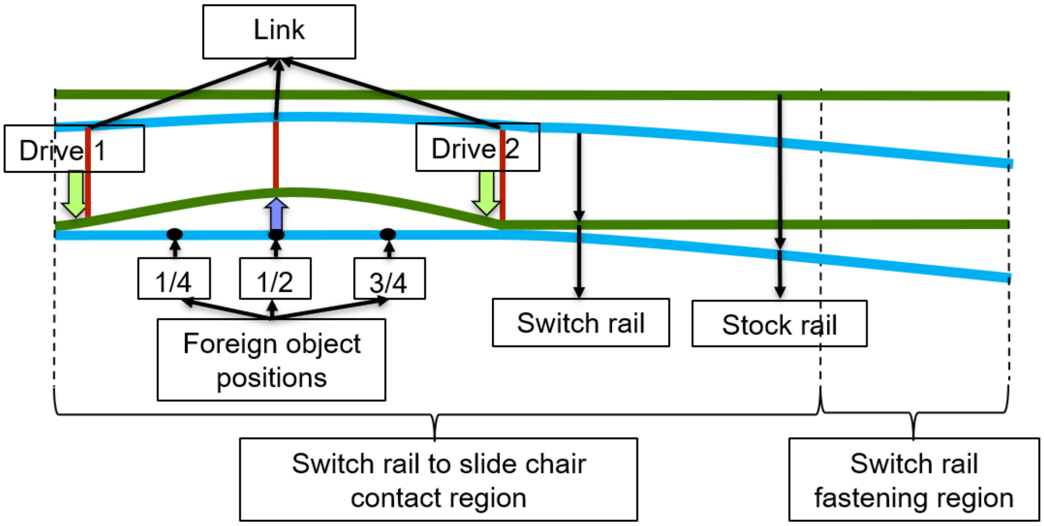

Figure 2. Topology of the MBS model illustrating the different parts as well as support condition regions (slide chair or fastening) for the switch rails along their length (refer to [3]). The switch rail deformation pattern when a foreign object is placed at the halfway position between the drives is indicated.

SIMULATION PROCEDURE

The impact of trapped foreign objects was assessed by simulating the full switch actuation using the following procedure:

1. The model is first brought to static equilibrium with the switch rails positioned for the through route.
2. A full switching cycle is simulated by actuating the drives in a displacement-controlled method, moving the switch from the through route to the diverging route and back. The Switch rail displacement vs time used for this actuation is shown in Figure 3.
3. A foreign object is introduced at the onset of the return movement to the through route. It is modeled as a unilateral spring that becomes active once the gap between switch and stock rail equals the size of the foreign object.
4. The investigated parameters—foreign object size, its normalized position between the drives, and the friction coefficient between the bottom of the switch rail and the slide chairs—are summarized in Table 1.

Table 1. Investigated parameter set

Parameter study	Value		
Object size [mm] (object at ½, friction coefficient fixed at 0.1)	0	15	30
Object position (object size 15 mm, friction coefficient fixed at 0.1)	1/4	1/2	3/4

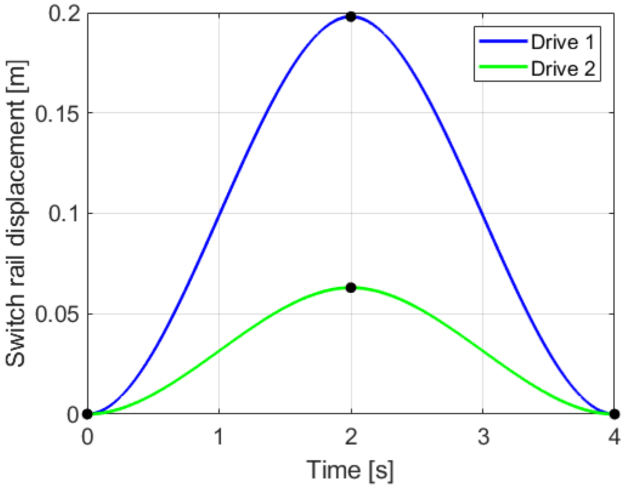

Figure 3. Time-displacement function applied to the drives.

5. Force-displacement relationships at both drives are analyzed for the different scenarios to evaluate the mechanical response and identify anomalies.

RESULTS

Influence of Trapped Foreign Object Size

Simulations were conducted for three different foreign object sizes (0, 15 and 30 mm) located at the 1/2 position between the drives (see Figure *4*2). Figure 4 illustrates the lateral deformation of the right switch rail at various stages of the actuation cycle. After 2 seconds, the rail has completed its movement from the through route to the diverging route. In the second half of the cycle, the deformation pattern reflects the rail's first contact with the foreign object. At the end of the cycle, a gauge narrowing is evident at the location of the object—matching its size—requiring the drives to exert additional force to overcome the obstruction and fully close the gap.

The force-displacement behavior of both drives is illustrated in Figure 5. In the baseline scenario (0 mm object), the force outputs remain relatively constant throughout the actuation cycle, indicating limited frictional resistance. However, when a foreign object is introduced, the drives must apply additional force to close the gap created by the obstruction. A noticeable kink in the force-displacement curves marks the point at which the switch rail comes into contact with the foreign object. Beyond this point, a nearly linear rise in force is observed as the drives attempt to overcome the added resistance.

In real-world conditions, the drives are considered to be in control if the drive displacement is below the threshold limit of 3 mm with the maximum drive force being 6 kN. In the case of the 30 mm foreign object, the required drive force to close the gap at the drives when the displacement is around 3 mm is more than the maximum force limit. This implies that the drive would stop and not go into control for an object of this size. For 0 and 15 mm objects, the drive forces and displacements are within the acceptable limits and would go in control.

By comparing the timing of the kink across different object sizes, it becomes apparent that the size of the foreign object can be estimated: the larger the object, the earlier the kink appears in the drive force curve. The presence and timing of the kink, along with the subsequent force increase, can be used as input features for pattern recognition techniques aimed at detecting and characterizing trapped foreign objects.

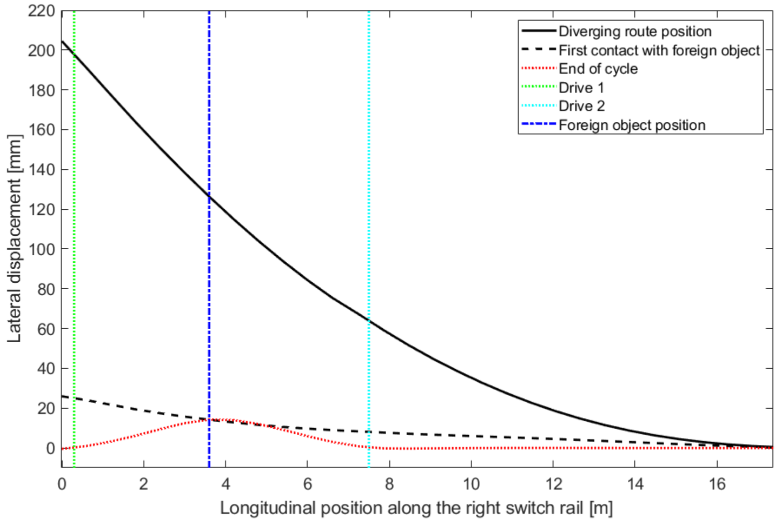

Figure 4. Example of lateral switch rail displacements at different points of the loading cycle for a 15 mm object. Deformation of only the right switch rail is presented as it comes into contact with the foreign object.

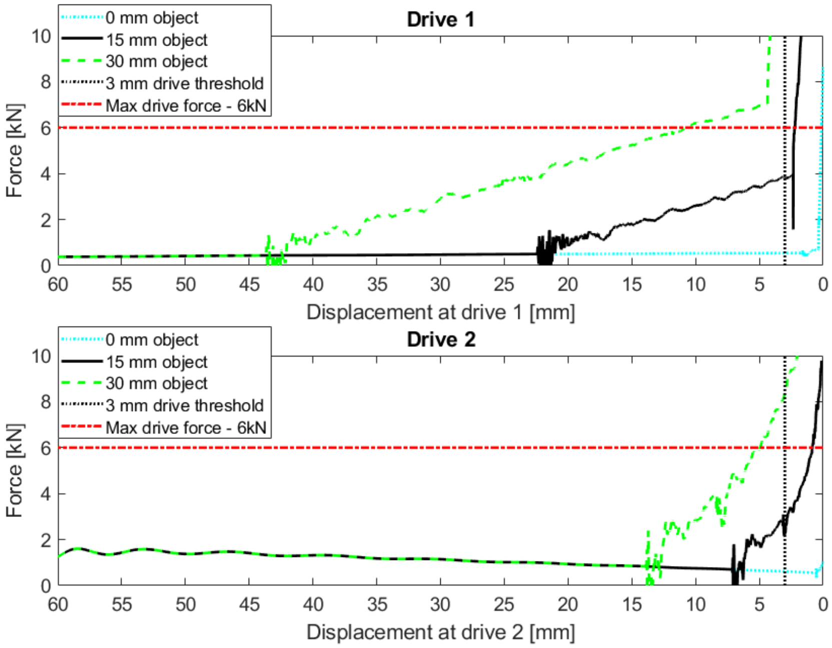

Figure 5. Force vs. displacement relationships for the drives for different object sizes. Note that only a part of the actuation cycle where the switch rail is coming in contact with the foreign object is shown.

Influence of Object Position

An investigation was conducted into three object positions between the drives —namely at one-fourth, half, and three-fourths of the distance for a 15 mm foreign object. Drive force vs. displacement for each position are shown in Figure 6. When the object is located at the one-fourth position, drive 1 requires approximately 100 kN of force to close the gap caused by the foreign object. Conversely, placing the object at the three-fourths position results in a significantly higher force demand from drive 2. These results indicate that closer the foreign object is to a drive, the force required to bring the drive into control i.e. displacement within the limit, increases substantially above the maximum limit. Given the maximum 6 kN actuation force, the drives would not go into control for these cases.

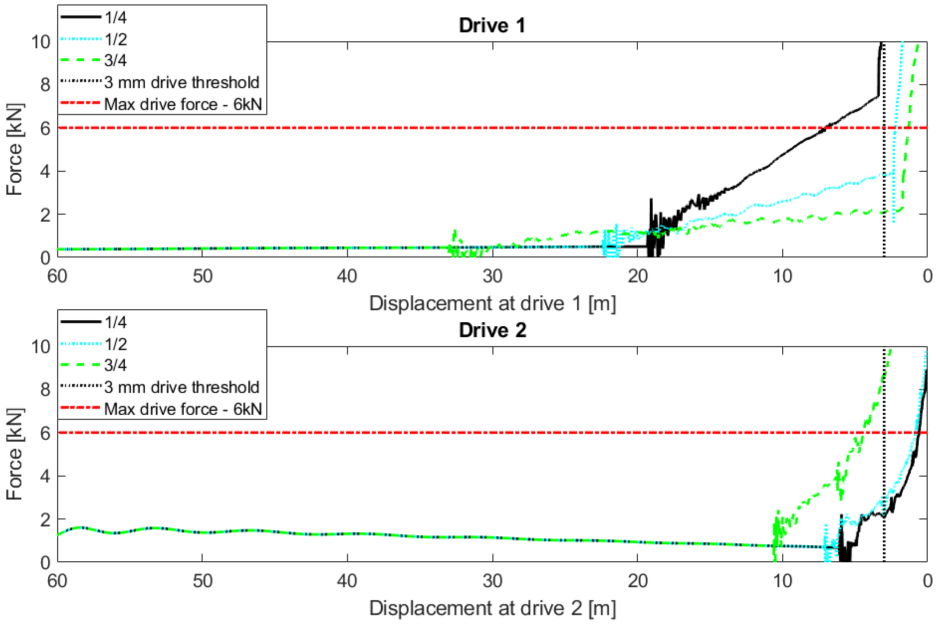

Figure 6. Force vs displacement for the drives for different object positions. Note that only a part of the actuation cycle where the switch rail is coming in contact with the foreign object is shown.

CONCLUSIONS

The aim of this paper was to utilize an MBS to obtain force–displacement relationships for the drives when a trapped foreign object is present. Simulation results revealed that contact with a foreign object produces a distinct kink in the drive force output. By analyzing the onset of the kink and the subsequent force behavior, it is possible to infer both size and position of the trapped object between the drives. These observed behaviors can be leveraged to train a neural network or another form of meta model to detect foreign objects in railway switches. Future work will focus on developing a robust detection method based on these insights and validating its effectiveness under real-world operating conditions.

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