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Simulation of Wheel Climb at Worn Switch Points

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Summary

Diverging route switch points are subjected to heavy contact from passing wheel flanges and can wear into a profile with a shallow gage face angle conducive to wheel climb. Transportation Technology Center, Inc. (TTCI) ran NUCARS®* simulations of wheel climb at worn switch points using conservative, worst-case-scenario conditions to investigate the effects of parameters including track layout, coefficient of friction (COF), speed, and gage face angle. This work was conducted as part of the Association of American Railroads' Strategic Research Initiative on Wheel/Rail Profile Design and Maintenance.

The track used for the modeling was a reverse curve layout (i.e., an "S-curve") with a turnout to the inside of the second curve. This simulation was intended to address a small subset of turnouts that were constructed within the physical limitations of some railroad yards. The entry angle of the turnout is exacerbated by the curvature of the second curve producing a worst case layout for wheel climb. The track geometry modeled for this exercise should be considered as one type of worst-case scenario prone to wheel climb and would not make a sufficient basis for establishing a North American freight railroad guideline for switch point gage face angle. When the combination of the gage face angle of the switch point was 70 degrees and the COF was less than or equal to 0.5, no wheel climb incidents were predicted for a worst-case railcar with asymmetrically worn wheels and an imbalanced load. A more typical railcar did not appear to be a wheel climb risk for switch face angles of 60 degrees and higher at turnouts located in track curvatures up to 4 degrees. In general, shallower gage face angles and higher COF values increased the probability of wheel climb. Speed restrictions appeared to have a limited effect on reducing the tendency for wheel climb at this type of turnout.

Based on the NUCARS modeling results, turnouts toward the inside of sharp curves should be protected to avoid wheel climb derailments. Several ways to protect such turnouts include the following:

- Install a mechanical device (switch point protector, guardrail) to restrict contact between the wheel flange and the switch point
- Maintain a switch point gage face wear angle no less than 70 degrees and install a wheel flange lubricator nearby to reduce the COF. This strategy relies on maintaining continual effectiveness of a wayside flange lubricator, and thus should be considered as a secondary protection method.



INTRODUCTION

TTCI has conducted a parametric simulation of wheel flange climb derailments at worn switch points to evaluate the effect of a number of factors related to track and rolling stock. Worst-case-scenario conditions were modeled in order to produce conservative results.

BACKGROUND

No. 9 switches are commonly used in railroad yards. They have a kink angle of slightly over 1 degree at the point of switch and a switch rail length of 19.5 feet with a radius of about 1,100 feet, which is followed by a 632-foot radius curve for the diverging route. Most switch point derailments occur on the diverging route.

There is no superelevation for yard switches. The operating speed in yards is generally below 20 mph depending on yard traffic conditions. Switches in freight yards generally do not have gage face lubrication. The gage face lubrication was applied at one passenger service yard visited by TTCI engineers.

American Railway Engineering and Maintenance-of-Way Association does not have guidelines specific to the worn gage face angle of a switch point. American transit agencies and freight railroads outside North America have standards for gage face wear angle limits between 58 and 64 degrees.¹

The ratio of the lateral-to-vertical wheel/rail forces (L/V) is one of the primary determining factors for wheel climb. Wheelsets tend to experience high lateral forces in tight and S-curves due to high angle-of-attack. Based on the Nadal criteria² expressed in Equation 1, the limiting L/V ratio for wheel climb reduces as wheel/rail contact angle decreases and coefficient of friction (COF) increases.

$$\left(\frac{L}{V}\right) = \left(\frac{\tan(\delta) - \mu}{1 + \mu * \tan(\delta)}\right) \quad (1)$$

In Equation 1, L is the lateral wheel/rail force, V is the vertical wheel/rail force, μ is the COF, and δ is the wheel/rail contact angle.

Side-to-side load imbalance and track cross level changes can result in a reduction of vertical force and a corresponding increase in the L/V ratio.

The asymmetrical wheel wear pattern³ has a tendency to increase lateral force when the wheel with a thinner flange contacts the outer rail of a curve, because of negative rolling radius difference.

RAILROAD YARD VISIT

TTCI engineers visited railroad yards to investigate the track, switch, and wheel conditions that may have contributed to wheel climb at the switch points. Yard derailment records provided by these railroads showed some of the following features at derailment locations:

- Switch located in tight curves
- S-curve layout
- Low switch gage face angle due to wear
- Worse than mainline track geometry variations
- Worn switch point

Poor track geometry can induce additional lateral forces and wheel lift. A worn switch point, as Figure 1 shows, can provide support for wheels with a thin flange tip to promote wheel climb. These two issues are related to track and switch maintenance and generally can be measured and observed and are not addressed further in this digest. The first three factors above are investigated in this digest. Currently, there is no guideline for the gage face wear limit angle of a switch point for freight service and there is no convenient tool for maintenance personnel to take this measurement.

Figure 2 shows a freight yard layout with multiple switches and frogs in a short distance. The red arrow points to the switch where one incidence of wheel climb derailment occurred. It should be noted that the turnout in Figure 2 is located in tangent track, not in a reverse curve. The turnout forms the S-curve for the diverging route and is a more common (and less severe) layout than the S-curve situation that was the focus of the modeling described in this digest.



Figure 1. Switch Point Damage



Figure 2. Switch Layout in a Freight Yard

Figure 3 shows a more complicated switch layout in a passenger rail yard. Based on the traffic conditions, trains may be routed in tight curves and S-curves.



Figure 3. Switch Layout in a Passenger Yard

Figure 4 shows a switch point that had worn into a lower face angle compared to the new switch face angle of 75 to 78 degrees. During the visits to the yards, TTCI engineers used a portable electronic profile measurement device to measure worn switch point profiles. Gage face angles were found to be in the range of 55 to 70 degrees.

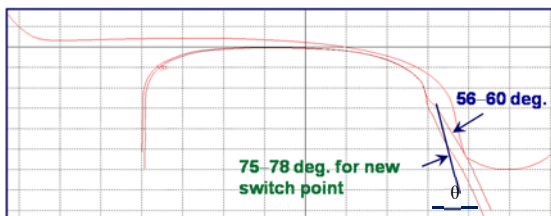


Figure 4. Low Gage Face Angle of Switch Point

MODELING INVESTIGATION

Based on the field observations and measurements, NUCARS simulations were conducted to investigate the wheel climb tendency at switch points under the influencing factors discussed in the previous section. Table 1 lists the track, rail and wheel parameters, and the ranges used in the simulations.

Each simulation, involving a specific combination of the parameters in Table 1, was conducted on a reverse curve track layout with the railcar making a facing point move to the diverging route of a No. 9 turnout on the inside of the second curve as shown in Figure 5. The first and second curves were

always the same curvature and “perfect” track geometry was used with no surface, gage, or alignment deviations. An open-top coal hopper with moderately worn 3-piece trucks was used for the model.

Table 1. Simulation Parameters and Range

Parameter	Values Modeled
Track curvature	3-degree to 8-degree curves in 1-degree increments
Switch rail gage face angle	55 degrees to 70 degrees in 5-degree increments
Speed	5 mph to 20 mph in 1 mph increments
COF of the top and face of the rails	0.3-inch to 0.6-inch in 0.1-inch increments
Gross rail load	Empty (63,000 lb), loaded (263,000 lb) symmetrically, and loaded (263,000 lb) with the weight shifted 23% to the inside rail of the second curve
Wheel profile	Symmetrically and asymmetrically worn

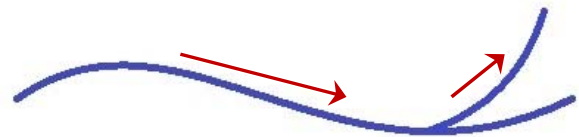


Figure 5. Track Layout – Diverging Route toward the Inside of a Curve Immediately Preceded by a Reverse Curve

MODELING RESULTS

Results of thousands of cases of NUCARS simulations were analyzed to investigate the wheel climb risk. For this analysis, it was considered a high risk of wheel climb when the predicted L/V values met or exceeded the Nadal limits for a sustained distance of at least 3 feet. For the μ and δ values used in the simulations, Nadal limits of L/V ratios ranged from 0.45 to 1.34. Figure 6 shows an example of wheel climb at a diverging route switch point.

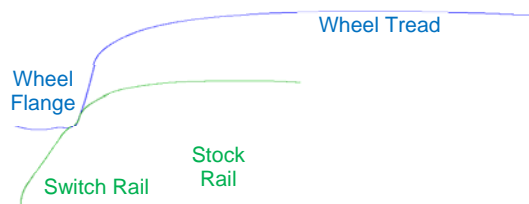


Figure 6. Wheel Climb at Switch Point

Figure 7 displays two sets of the analysis results. They show the relationship of switch face angle, friction coefficient, and speed for the given type of railcar and track curvature. The data on the surface of Figure 7 indicates the maximum speeds without a high risk of wheel climb for that specific condition based on the simulations. For example, the blue surfaces in these two figures indicate speeds without a high risk of wheel climb would be less than 5 mph for the corresponding face angles and friction coefficients.

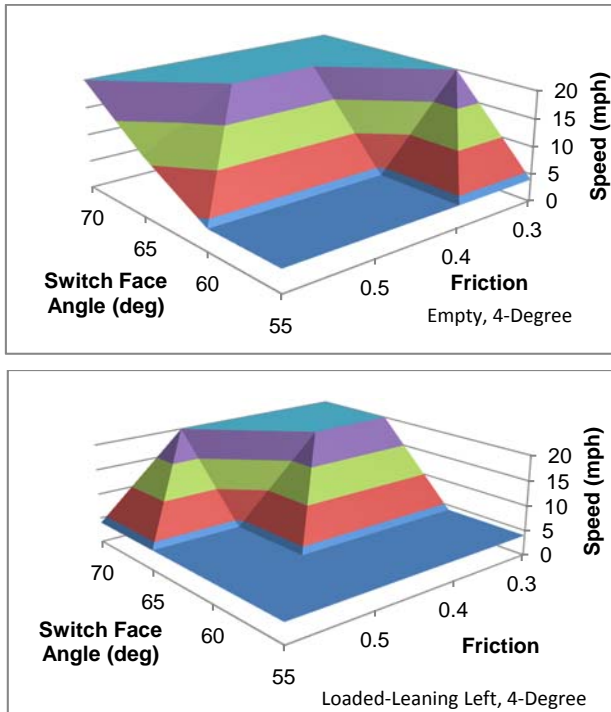


Figure 7. Relationship of Switch Face Angle, Friction Coefficient and Speed for Given Type of Car and Track Curvature

The simulations were highly sensitive to gage face wear angle and COF. The railcar with an imbalanced load proved to be slightly worse than the empty railcar, and it was markedly worse than the uniformly loaded railcar.

For both the empty and imbalance loaded railcars, the wheel climb risk was high for speeds above 5 mph when the switch face angle was 65 degrees and below and the COF was 0.5 and above (dry condition). The wheel climb risk was high when the switch face angle was 60 degrees and below in the entire COF range simulated from 0.3 to 0.6 for speeds above 5 mph.

For the uniformly loaded railcar, the wheel climb risk was high at speeds above 5 mph when the switch face angle was 60 degrees and below, the COF was 0.5 and above, and the switch was located on a curve of 5 degrees or tighter. On shallower curves, the uniformly loaded car did not appear to be a wheel climb risk for switch face angles of 60 degrees and higher.

For the imbalance loaded railcar, neither speed nor track curvature made a substantial difference in the results. Only 8 out of all 288 combinations of contact angle, track curvature, COF, and car lading showed a relevant limiting speed between 5 and 20 mph. All the other simulation cases either produced a wheel climb at the minimum simulated speed (5 mph, 138 cases) or did not produce a wheel climb up to the maximum simulated speed (20 mph, 142 cases). Curvature had a larger influence for the empty railcar and the uniformly loaded railcar.

The track geometry modeled for this exercise (turnout toward the inside of a sharp curve) should be considered as one type of worst-case scenario prone to wheel climb and would not make a sufficient basis for establishing a North American freight railroad guideline for switch point gage face angle. Instead, these modeling results are intended to address a small subset of problematic turnouts that were constructed within the physical limitations of some railroad yards.

CONCLUSION

Parametric NUCARS simulations of wheel climb at worn switch points using conservative, worst-case-scenario conditions predicted no wheel climb incidents for turnouts located toward the inside of sharp curves, when the combination of the gage face angle of the switch point was 70 degrees and the COF was less than or equal to 0.5. Speed restrictions appear to have a limited effect on reducing the tendency for wheel climb at this type of turnout.

In general, shallower gage face angles and higher COF values increased the probability of wheel climb.

RECOMMENDATIONS

Based on the NUCARS modeling results, turnouts toward the inside of sharp curves should be protected to avoid wheel climb derailments. Several ways to protect such turnouts include the following:

- Install a mechanical device (switch point protector, guardrail) to restrict contact between the wheel flange and the switch point
- As a secondary protection method, maintain a switch point gage face wear angle no less than 70 degrees and install a wheel flange lubricator nearby to reduce the COF

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3. Tournay, H., R.B. Wiley, T. Guins. October 2010. "Incidence of Asymmetric Wheel Flange Wear in Revenue Service." *Technology Digest TD-10-039* Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.

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