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Evaluation of Wheel Climb Potential in Yard Switches

Xinggao Shu and David D. Davis

Summary

Wear and switch point chipping are two common switch failure modes in railroad freight operations. Transportation Technology Center, Inc. recently conducted a study to investigate the effects of switch wear and chipping defects on the potential of flange climb in yard switches. The NUCARS® model and field measurements were used to evaluate worn switch performance. The following conclusions are drawn from this study. Also given is a method of determining the allowable length and depth of chipping defects.

- Current guidelines for allowable operating speeds in switches are conservative for nominal conditions. The risk of a flange climb derailment in yard switches is affected by two major factors:
  - Track geometry
  - Switch point surface condition (i.e., chipping)
- Switch rail wear without chipping defects increases the flange climb derailment risk but not as significantly as it does with the presence of chipping defects.
- Stock rail metal flow is a root cause of chipping and split switch failures.
- The current guidelines in the *AREMA Manual of Railway Engineering* on switch point removal because of chipping may be improved by considering the length and depth of the defects. Chapter 5 requires chips lower than 7/8 inch from the top of the rail be repaired regardless of chip length.[1] A chip length limit is needed to take into account the effects of three-dimensional wheel/rail contact on flange climb derailment.
- The current AREMA recommended practices are conservative for chips with depths of 7/8 inch or more.
- The current AREMA recommended practices may be nonconservative for shallower (than 7/8 inch depth) chipping. These defects may also pose a wheel-climb potential, if their lengths are sufficient to allow the wheel flange to engage and climb the defects.

The significant variables in determining allowable switch point chip out dimensions are:

- Chip depth below top of rail
- Chip length at a given depth
- Maximum permissible train speed
- Wheel-rail friction

This digest also describes the performance of yard switches under various wear and geometry conditions as well as some suggested operational and maintenance limits for yard switches with and without chipping defects on the switch points.

Please contact **Xinggao Shu (719) 584-0540** with questions or concerns regarding this *Technology Digest.* E-mail: xinggao_shu@ttci.aar.com.
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INTRODUCTION

Transportation Technology Center, Inc. (TTCI) conducted a study to investigate the effects of switch wear and chipping defects on the flange climb derailment risk through NUCARS® modeling and field measurements to evaluate worn switch performance.

Effect of Switch Wear

Wear and switch point chipping are two common switch failure modes in railroad freight operations.[2] The switch surface and alignment deteriorate as the switch rails wear from wheel/rail (W/R) interaction. To investigate the wear effect on switch performance, FRA Class 2 and 3 track alignment and surface defects and a switch point "wear" limit used by a major western railway were implemented in the switch wear modeling. The wear/alignment limit is a maximum 0.3 inch mid-chord offset, measured over a 2-foot length on the gage line of the switch.

In addition to the track perturbations, the following parameters were used in the modeling:

- Empty hopper car, with 7,874-pound axle load
- No.10 straight split switch
- New AAR 1-B wheel (NW) and a measured worn wheel with 3-mm hollow on tread (HW)
- New 136-pound/yard rail
- W/R friction coefficient of 0.5
- Running speeds from 15 to 25 mph

Figures 1 and 2 show the impact force on the switch and the wheel L/V ratio increased as switch wear and track defects developed. The wheel L/V ratios for cases with FRA Class 3 defects exceeded the Chapter 11 limit regardless of the existence of switch wear. Simulations also showed vehicles with new wheels derailed at 5 mph on track with FRA Class 2 defects without switch wear. The flange climb derailment potential on the switch was mainly caused by track defects. The effect of switch wear was negligible.

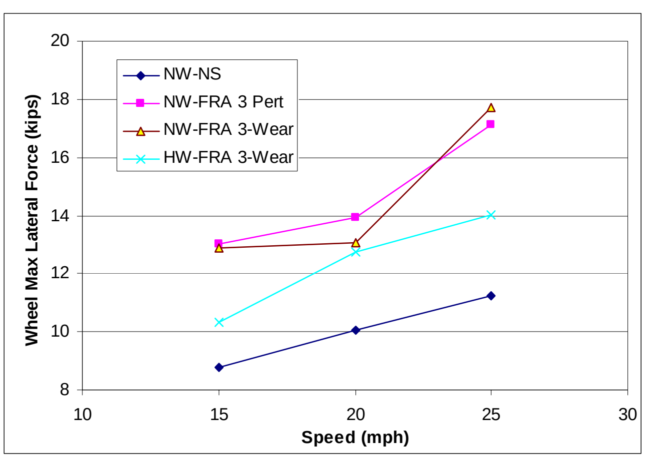

Figure 1. Effect of Switch Wear and Operating Speed on Lateral Wheel Force

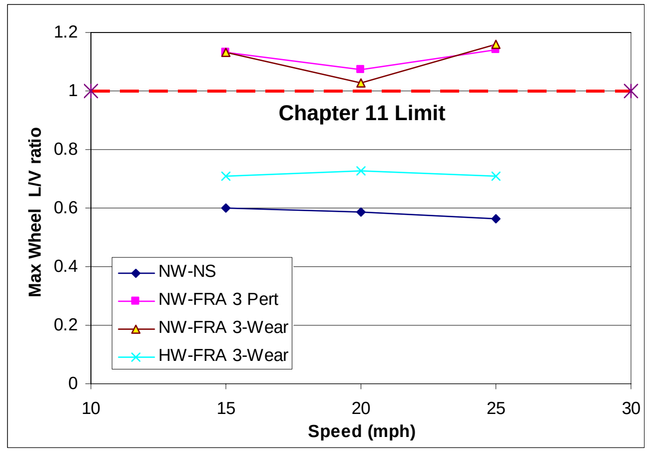

Figure 2. Effect of Switch Wear and Operating Speed on Wheel L/V Ratio

Effect of Switch Point Chipping

Chipping (local cracking and metal loss) is another common switch failure mode on the railroad. With the accumulation of tonnage on a switch, stock rail metal flow accumulates on the gage side of the switch. The accumulated stock rail metal flow intrudes into the back of the switch rail when the switch point is closed, cutting into the thinner top part of the switch point blade under train loading. This changes the stock rail/switch point contact from the entire undercut surface to a line contact at the depth of maximum stock rail metal flow. Eventually, this high stress contact causes the switch point to start chipping. The chipping mechanism explains field observations that chips are discontinuously distributed along the blade and are broken at approximately the same depth level (as measured from the top of the stock rail), as Figure 3 shows.

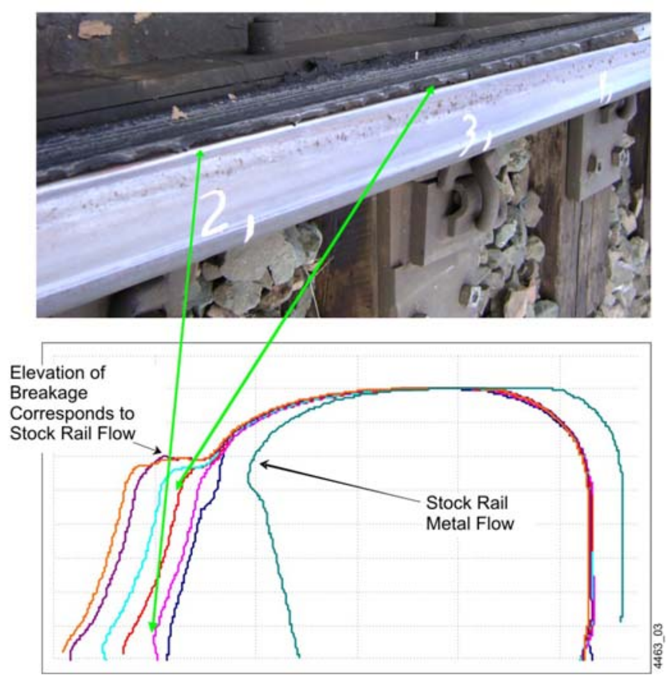

Figure 3. Chips (about 0.47 inch depth from top of rail) discontinuously distributed along the switch blade

AREMA Manual of Railway Engineering, Chapter 5, requires that chips lower than 7/8 inch from top of rail be repaired regardless of chip length.[1] Clearly, the lower the chip defect is down from the rail top, the easier a wheel with a lower flange contact angle can catch the chip and climb up to the top of the rail. However, a chip has to be long enough to allow the wheel contact on the switch at the position 7/8 inch down from the top of the rail due to the three-dimensional geometry constraints between the wheel and rail.

Figure 4 shows a typical three-dimensional W/R contact case on a switch with defects, such as chips. Usually an arbitrary three-dimensional surface such as chips on the switch rail can be described by using discrete grid node coordinates. For the convenience of field inspections, chip dimensions at several locations on the switch rail can be used as control indices.

Table 1 lists the chip length (*l*) limits for the AAR-1B wheel/136-pound/yard rail combination based on the three-dimensional W/R contact geometry analysis with 63 milliradian (mrad) axle angle-of-attack (AOA).

The axle AOA was generated due to the switch kink angle and axle dynamic yaw movements. The 63 mrad AOA, as calculated by using the maximum maintenance tolerance between the bearing adapter and truck frame, represents the worst scenario, such as small size switch (lower than No. 10 with large kink angles), low warp stiffness trucks, and worn components reaching maintenance limits.

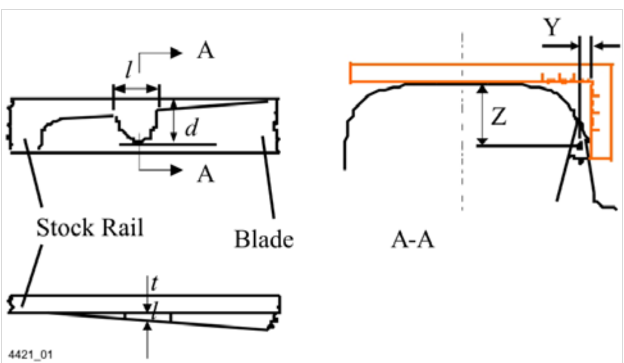

Figure 4. Chip Position and Dimensions on Switch Rail

Table 1. Geometry Constraints on Length (*l*) for Chips 7/8 inch (*d*) Down from Top of Rail

	Y=0.15 inch	Y=0.20 inch
Z=0.25 inch	6.75	6.28
Z=0.50 inch	3.45	1.82

For the AAR-1B wheel/136 pound/yard rail combination, the contact angle at the location 7/8 inch down from top of rail is about 53.17 degrees. If the chip lengths are smaller than the limits in Table 1, the wheel cannot touch the bottom of the 7/8-inch chip. Instead, the wheel contacts the switch rail at a position less than 7/8 inch from top of the rail with a contact angle greater than 53.17 degrees, due to the three-dimensional W/R contact geometry constraint.

W/R friction coefficient plays a critical role in flange climb derailments. Tribometer measurements showed the friction coefficient was mostly lower than 0.55 for normal dry rail conditions. But few friction coefficient measurements were conducted on switches, especially switches with chips, due to the limitations of the tribometer. To be conservative, a wide range of high friction coefficients from 0.55 to 0.99 were used for this study to cover all possible conditions for flange climb derailment simulations with chipped switches. The extreme 0.99 friction coefficient corresponds to the conditions of a sharp edge on a switch rail with freshly broken chips. The corresponding contact angle is about 45 degrees.

A previous study showed that a worn wheel's flange climb derailment distance is longer than that for a new wheel because wheel wear usually produces a higher flange angle and flange height.[3] The new AAR-1B wheel was used for this study to obtain a conservatively short flange climb derailment distance limit.

Figure 5 shows the climb distances on a chipped switch rail with different chip depths and W/R friction coefficients. The flange climb derailment distance decreases with increasing chip depth and W/R friction coefficient. The climb distance can be as short as 1.14 inches for chips with 7/8-inch depth at the extremely high friction coefficient of 0.99.

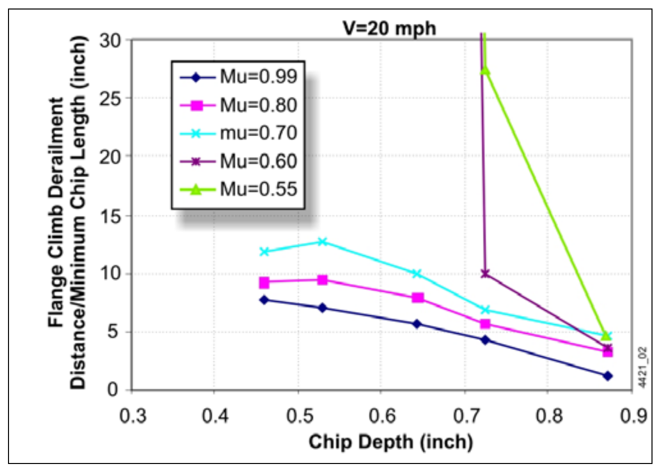

Figure 5. Effects of Chip Depth and W/R Friction Coefficient on Flange Climb Distance

The 1.14-inch flange climb distance indicates that the chip length has to be longer than 1.14 inches to allow the wheel to climb up the rail; correspondingly, the geometry constraint limits in Table 1 must be increased by 1.14 inches to take into account the climb distance, as Table 2 lists.

Table 2. Length (*l*) Limits for Chips 7/8 inch Down from Top of Rail

	Y=0.15 inch	Y=0.20 inch
Z=0.25 inch	7.89	7.42
Z=0.50 inch	4.59	2.96

Flange climb derailment risk is low for chips 7/8 inch deep and shorter than the length limits in Table 2 because the chip is not long enough to allow the wheel to climb up to the rail. Flange climb derailment risk is high for chips 7/8 inch deep or larger because the flange climb derailment distance can be as short as 1.14 inches. Table 2 lists the chip length limits.

The chip thickness can be ignored because it is small and easily exceeds the limit whenever chips occur. The chip lengths at locations with depths down from top of rail can be used as control indices for field inspection. To apply the above criteria, the following procedures are recommended:

- Step 1. Check the chip depth. If the chip reaches 7/8 inch or lower on the blade from the top of the rail, continue to Step 2; otherwise, further evaluation is needed.
- Step 2. Check the chip length. If the chip length at the 7/8-inch position exceeds 1.14 inches, and the chip length at locations in Table 2 exceed corresponding limits, repair the chip; otherwise, further evaluation is needed.

The above maintenance criteria are less conservative than the AREMA Chapter 5 criteria because both chip depth and length, rather than just chip depth (7/8 inch), have to exceed the limits. The AREMA Chapter 5 criteria, which are based on a 7/8-inch chip depth regardless of chip length, are only conservative (safe) for switches with chips reaching 7/8 inch or lower from the top of the rail, but not conservative enough for long chips even though their depths are smaller than 7/8 inch.

Figure 5 shows chips with depth smaller than 7/8 inch can also induce flange climb derailment when their lengths exceed the flange climb distance. For chips with depths smaller than 7/8 inch, further evaluation is needed to take into account the effects of chip depth and length, W/R friction coefficient, axle AOA, and operating speed.

Figure 5 also shows that flange climb derailment risk on a No. 10 switch at normal operating speeds is low for chips with depths less than 0.63 inch and at W/R friction coefficients less than 0.6. Flange climb derailment risk decreases with the W/R friction coefficient. Lubrication can be used as a temporary method of preventing flange climb derailment on a chipped switch; however, it is not a safety policy because the W/R friction coefficient depends on many variables, such as lubricator reliability, traffic, and weather.

Figure 6 shows that:

- For chips with depths greater than 0.73 inch, and lengths longer than 4 inches, the wheel climbs up the chip and derails at operating speeds as low as 5 mph at the extremely high friction coefficient of 0.99, which means limiting speed does not help prevent derailment under these conditions
- Flange climb derailment on switch chips with depths less than 0.63 inch at extremely high friction conditions (0.99) can be prevented by limiting operating speed to 5 mph

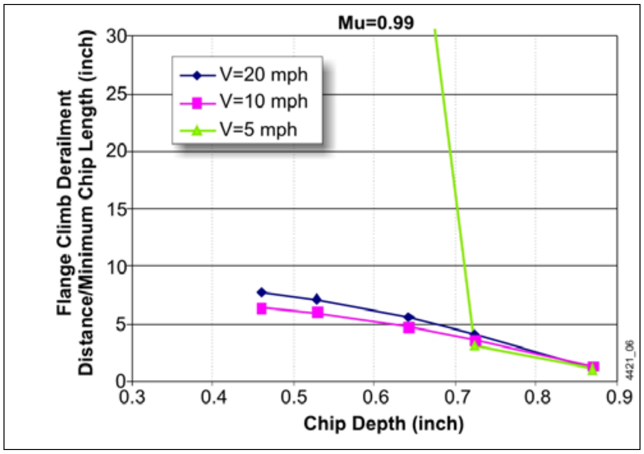

Figure 6. Effects of Speed on Chipped Switch Flange Climb Distance, 0.99 Friction Coefficient

FUTURE WORK

This study focused on the effects of switch wear and chips on switch performance. The critical question of when the switch starts chipping has not been answered. To predict the evolution from crack initiation to chip formation on switches, more laboratory tests, vehicle track dynamics and structural strength analyses, including material fatigue and fracture mechanisms are recommended.

ACKNOWLEDGMENTS

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