Switch protection using the top of rail friction modifier system

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The work described in the following article was carried out using KELTRACK® top of rail friction modifier system.

INTRODUCTION

Switches and crossings are an integral part of rail infrastructure providing the means by which rail vehicles traverse from one track to another. As a safety critical asset it is vital that switches and crossings are well maintained and suffer minimal damage. In general terms, a switch will always represent a location of a geometrical track deviation (compared with plain line). Analogous to a curve, a vehicle will respond to such a track deviation with the formation of an angle of attack (AOA) at the leading wheelset of each bogie resulting in the generation of lateral forces and possible flange contact.

Dependent on switch geometry and vehicle type, switch blades can suffer from plastic flow leading to fatigue (RCF) crack formation due to excessive flange contact in an area about 2-5m away from the switch tip. Although switches are maintained according to best practices, additional repair work (repair welding) is required to correct the formation of these defects. However, the repeatability of these cost intensive corrective actions is limited, (NR procedures only allow repair welds for R260 grade blades). These repairs can only be performed a limited number of times, (no repair welds are carried out on R350HT blades), leading to further additional costs related to the early replacement of switch blades. The result is that the life of some switches is significantly less than expected.

This article will focus on WN572A at Nuneaton Cemetery Junction; a switch where the life was significantly less than expected due to the fatigue failure of the switch blade approximately 2m from the switch tip. The half switch was replaced every 18 months after three defect weld repairs at significant cost. The objective was to seek a solution, using observations made at Barnt Green.

BARNT GREEN NOISE REDUCTION SCHEME

Before we look at Nuneaton it is important to understand and review the noise reduction project at Barnt Green. The information from Barnt Green led to the belief that it is possible to protect against the most common cause of switch rail failure.

Barnt Green has a tightly curved section of track on the Redditch branch with a curve radius of around 150m. It suffered from excessively high levels of noise. In 2008 Network Rail installed a top of rail friction modifier system. The top of rail friction modifier system is applied using similar electrically powered cabinet equipment to normal gauge face lubricants, however, this top of rail friction modifier system is applied to the rail head. The system achieves a consistent intermediate co-efficient of friction of 0.35, instead of aiming to achieve minimal friction levels (typically grease gives a co-efficient of friction of below 0.15). The coefficient of friction of dry rail is significantly higher - normally between 0.5-0.65. This is detailed in **figure 1** where it can seen that it is desirable to apply a lubricant to the gauge corner/wheel flange interface and the friction modifier to the rail head/wheel tread interface.

The friction modifier is water based and designed to be applied to both rails as it does not impact on braking or traction. Application to both rails is key for use in ladders where the high and low rail change back and forth.

After the friction modifier system was fitted at Barnt Green there was a consistent reduction of noise levels of around 15dB [1]. (Noise is measured on a logarithmic scale and every 3dB reduction represents a halving of the noise energy). In this case the noise energy was reduced to 1/32 (~3%) of the original level.

However, in August 2010 the noise levels returned to their previous unacceptable level when the system was not refilled with the friction modifier. It was also noted at the visit to refill the equipment that there had been increased contact between the gauge corner and the train wheels. This was evidenced by increased wear to the gauge corner of the rail. It was decided to carry out a manual application of the friction modifier so that the rail was "preloaded" and the time to roll out the friction modifiers through the site would be eliminated. After the treatment to the low rail had been completed and before the treatment to the high rail had commenced, whilst awaiting a train to approach, the site team were able to observe the interface between the untreated track and the treated track. It was observed that each bogie rotated when the leading axle went onto the treated section of rail. The rotation was quite marked and was the same for each bogie. The direction of the bogie rotation was such that the axle became more perpendicular to the rail; essentially the wheelset was steering better.

It was clear that the only variation from normal was the presence of the friction modifier and that the effect of the friction modifier was to improve the steering of the bogie and to reduce the angle between the rail and the wheelset such that there was little or no contact between the wheel flange and the high rail – this is known as reducing the "angle of attack" **(figure 2)**.

NUNEATON – WN572A

The Wigston North Junction – Nuneaton South Junction (WNS) route connects the Midland Main Line and West Coast Main Line routes and is a mixed traffic line carrying freight and passengers. Specifically, the traffic is a mixture of Class 170 multiple units and freight trains. Annual tonnage is around 9 million tonnes and the line speed is 40mph at Nuneaton Cemetery Junction.

Switch WN572A is at Nuneaton Cemetery Junction on the Up Road **(see figure 3)** and is a shallow depth RT60 design inclined "F" switch (1:21.5) operated predominantly in the trailing direction. The switch is on the curved section of track with the affected switch rail being the high rail.

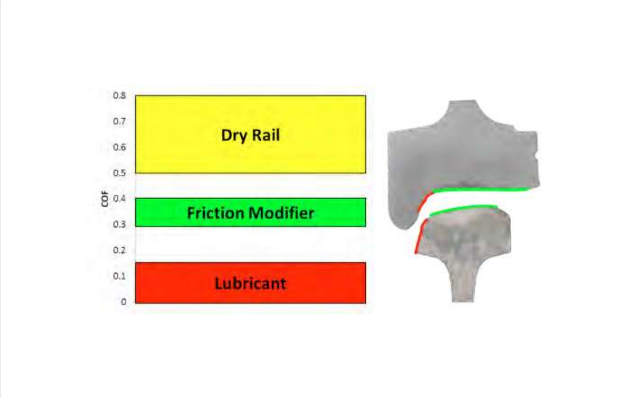

Figure 1: Wheel-Rail Friction - right material for the right face

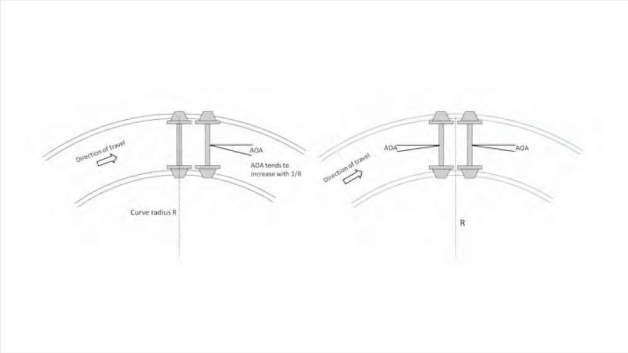

Figure 2: High AoA in tight curve (left)
Reduced AoA after the friction modifier application (right)

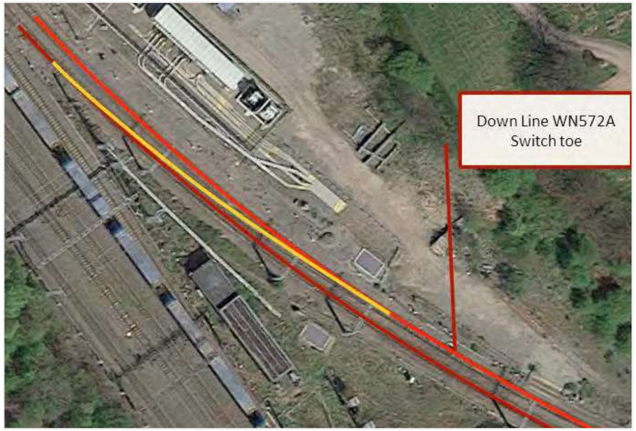

Figure 3: WN572A Cemetery Junction

The switch is well lubricated from a lubricator situated at Abbey Junction (approximately 1400m prior to WN572A). However, between 2004 and 2012 the high-rail half-set has had to be completely replaced every 15-18 months and there have been intermediate weld repairs about every 4 months. The life cycle of Cemetery Junction can be seen in **figure 4**. The damage, shown in **figure 5**, has always been on the high rail approximately 2m from the switch tip. This is classified as a Hazard 4 failure in terms of S/053 inspections with respect to the switch blade damage and has the UIC code of 504.

DIRECT RESULTS OF THE DAMAGE

The first action was to ban the switch to facing moves as this is classified as unsafe once the longitudinal length of the crack is greater than 200mm [2].

This then results in the following:

- Impact on the operation of the junction
- History of damage dictates an enhanced inspection regime is required
- Remedial weld repairs / switch change out come in with little notice as the defect grows quickly
- The short notice of required works increases safety risks associated with short term planning
- Disturbs planned work

Typically the half set at Nuneaton was being replaced after three weld repairs as the repair procedure can only be undertaken a limited number of times. This situation was unsatisfactory. The first action was to determine the cause of the damage.

CAUSES OF THE DAMAGE

It was clear from the initial observation of the defect that the lateral loading of the switch was excessive and that this was a fatigue issue.

Discussions within Network Rail revealed that this is a known issue at a number of sites and that it was thought to be a design issue with RT60 / NR60 layouts - they work well in the facing direction but some fail when there is traffic running over the switches when they are in the trailing direction. This seems to be a function of the location and traffic patterns as changing the half set does not eliminate the issue – i.e. it is not a manufacturing defect. The main cause was the angle of attack between the wheel and the rail being too high and resulting high loading caused by the wheel flange rubbing along the machined section of the switch rail being above the fatigue limit of the rail steel.

Given the relatively low cycle fatigue failure that is exhibited, (around 300,000 cycles at WN572A before a failure requiring a weld repair), it is not unreasonable to suppose that this is due to some plastic deformation occurring due to the relatively small, and ever reducing, cross sectional area of the last 1-2 metres of the switch.

The damage issue does not normally arise when trains are travelling in the facing direction as the angle of attack does not develop in the thin section of the rail. When the angle of attack has developed, the physical dimensions of the switch rail are greater and so are capable of withstanding the forces created.

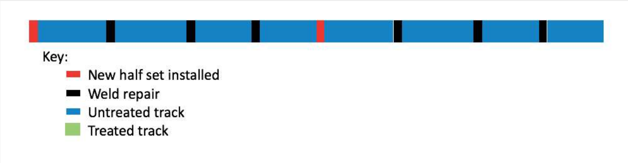

Figure 4: Cemetery Junction life cycle

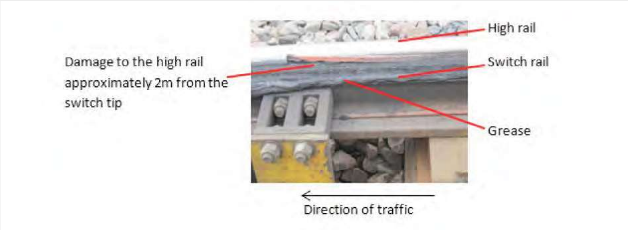

Figure 5: WN572A switch blade damage

Figure 6: Left photo - untreated rail at WN572A at the position where damage occurs. Right photo both rails treated with the friction modifier at WN572A at the position where damage occurs.

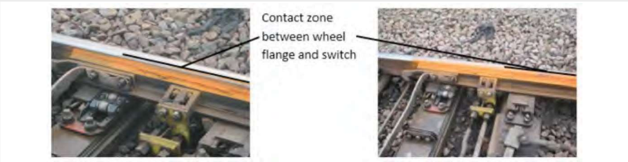

Figure 7: Left photo - untreated rail at WN572A at the switch toe. Right photo - both rails treated with the friction modifier at WN572A at the switch toe.

In the trailing direction, however, the angle of attack has already developed when the machined section of the switch rail is encountered, whilst the radius of curvature reduces on the approach to the switch tip the reduction in the angle of attack is insufficient to counteract the reduced cross sectional area of the switch rail resisting the lateral loads. The increasing load caused by the contact forces between the wheel flange and switch rail create a fatigue cycle that rapidly propagates to a horizontal failure approximately 15mm below the top of the switch rail. Once the crack has initiated, it grows horizontally including against the direction of traffic towards the area of increasing cross sectional area of the machined rail. The horizontal crack turns to the vertical at the end of the crack closest to the switch tip. The horizontal growth continues away from the switch tip until such time as the top of the switch rail breaks off.

APPLICATION OF LESSONS LEARNT FROM BARNT GREEN

It was decided to undertake a simple test at WN572A Nuneaton Cemetery Junction to see if the friction modifier had a similar effect at switch rails as the angle of attack was thought to be too high and might be the reason for the very high failure rate. The observations at Barnt Green demonstrated that the friction modifier had the capability on plain line to reduce significantly the angle of attack. The test was undertaken by painting the high rail with a spray paint so that the position where the wheel flange had contacted the switch rail could be observed. Initially there were no friction modifiers applied so that reference results could be recorded. The vehicle types were recorded so that similar vehicles could be compared with and without the friction modifiers. The results were recorded by taking photographs at the position where damage normally occurred (2m from the switch tip) and at the switch tip. There was some noise from the rails when the Class 170 unit passed by with the noise coming from flange contact.

After the reference results without the friction modifier had been recorded for a Class 170 3-car DMU the site was resprayed and the friction modifier manually applied to both rails 50m ahead of the switch, through the crossing and 5m beyond the switch tip. A Class 170 3-car DMU was observed through the site and it was noticeably quieter than without the friction modifier with less flange contact noise being heard. The results were again recorded at the point of damage 2m from the switch tip and at the switch tip. The results can be seen in **figures 6 and 7**.

It can be seen in **figure 6** at the position where the damage had been occurring that there was continuous contact between the wheel and the top of the switch rail when the rail was untreated and that the friction modifier had the effect of reducing the contact between the wheel and the rail making it intermittent. This was what was hoped for and demonstrated that the angle of attack had been reduced.

Figure 7 demonstrates the same effect of reducing the wheel flange contact at the switch tip. The angle of attack was reduced by the treatment, resulting in the reduction of the contact between the rail and the wheel on the friction modifier treated rail.

It is clear that if there is reduced or eliminated contact between the rail and the wheel then the bending forces are reduced or eliminated and so the rate of damage is reduced or eliminated.

A PERMANENT SOLUTION

In February 2013 when the friction modifier system was installed at Nuneaton, there had been a half set replacement of the switch some three months earlier in November 2012. The system that was installed was positioned to ensure that the friction modifiers covered the approach to WN572A so the steering of the wheelsets was optimised through the whole switch **(see figure 8)**. The installation also took into account the positions of signals and signalling equipment and was positioned to ensure that the filling of the equipment could be done without going trackside. It was important that the friction modification and lubrication were considered as a system – both components are required to minimise the wear to the switch.

A timeline since installation can be seen in **figure 9**. Since installation WN572A was defect free for 26 months until after one month of no friction modifier application, (4 months in total where there had been no treatment since the new switch blade was installed), the first S/053 inspection Hazard 4 failure was reported. Since the repair was undertaken and the installation has been maintained there have been no further failures of Hazard types 1,2 or 4.

THE BENEFITS AT NUNEATON

The key benefit of using friction modifiers at Nuneaton was the halt of the repeated failure of the equipment.

Other benefits include:

- Approximate net value of savings £40k – excluding any costs associated with delays. Approximately 10 weld repairs and two half switch replacement have been avoided up to November 2016 since the equipment was fitted
- Reduction in repairs, there has been an increase in life of at least 650% at the Nuneaton site
- Life increase for switches increased from 18 months to a projected 11 years
- Less inspection (over time and with increasing confidence, the inspection regime can be reduced)
- Fewer man-hours on track (safety benefit)
- Reduced risk of delay and constraint of operation
- Reduced disturbance to planned work
- Payback time estimated to be around 11 months

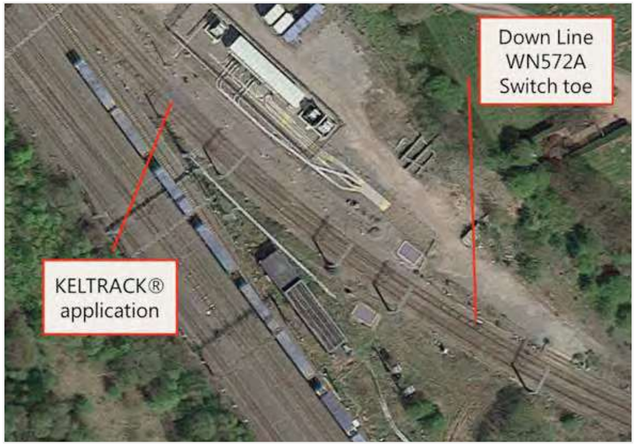

Figure 8: The friction modifier installation site and switch location

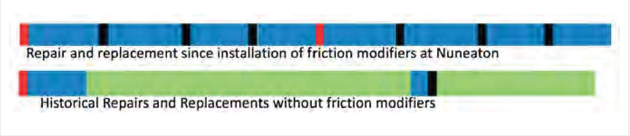

Figure 9: Post installation timeline

OTHER SITES NOW BEING TREATED

Since this first installation a number of other sites have been identified as having similar issues to WN572A and have been treated using the friction modifier system. These include Crewe Coal Yard, Reading West Curve and Birmingham Proof House.

The system at Crewe Coal Yard consists of a single applicator unit that is treating a pair of switches as part of a ladder, one predominantly facing and one trailing. The results have been such that the Delivery Unit weld repair team commented that "they were always going to the switches but they hadn't been there since the new equipment had been installed". The failure rate has been reduced dramatically and there have been no defects reported since the equipment was installed.

The installation at Reading West Curve has also proved to be very successful. Previously the half set was having to be replaced after as little as 2½ months when using standard grade steel. The rate of damage was such that a weld repair was not possible, so each time the switch had to be replaced. Using harder HP rail extended the life of the half set to 4 months but the HP rail cannot be weld repaired so was replaced with a standard grade half set in early May 2015.

A friction modifier system was installed in late June 2015 and the first damage was identified some 8 months later (this included a period of time when the equipment was inoperative due to lack of the friction modifier. This was due to the consumption rate not being fully understood and planned for in the initial period after installation. As the crack propagation rate was much lower due to the reduced contact forces, there was time following the identification of the defect to plan and carry out a weld repair of the switch rail meaning that it did not have to be replaced. This in itself means that the expected switch life can be quadrupled. The weld repair was undertaken in February 2016.

The result is that at a ratio of 3 weld repairs between each change of half set (as observed at Nuneaton) the life will have been extended from 2-3 months to 3 years. This estimate ignores that there was a period of time when the switch was not being protected by the friction modifier. It is estimated that the savings at Reading are approximately £100,000 pa; this refers purely to the reduction in ironwork and repair work and does not take into account any reduction in delay minutes and the financial / reputational benefits that that will bring.

IS THE USE OF THE FRICTION MODIFIER SYSTEM RESTRICTED TO RT60 / NR60 DESIGNS?

After looking at the way that the friction modifier system works, it was considered very unlikely that the friction modifiers would only work when applied to RT60 / NR60 design switches – there appears to be nothing in the design of the switch that makes them more likely to fail than non-RT60 / NR60 designs.

There have been numerous other sites identified on Network Rail infrastructure that exhibit similar defect histories to WN572A at Nuneaton and it is suspected that these sites may also benefit from installing friction modifiers to protect them. These sites are not restricted to RT60 / NR60 designs.

Internationally, it has been identified that a number of European countries have similar issues at switches where there is damage. This is consistent with the theory that there is damage caused to non-RT60 / NR60 design switches on Network Rail infrastructure i.e. this is not simply an NR60 design issue but an issue that applies to other designs as well.

THE EFFECT OF FRICTION MODIFIERS ON THE STEERING OF THE BOGIE

The friction modifier is used to tackle noise, RCF and corrugation by reducing the angle of attack between the wheel and the rail.

PRINCIPLES OF STEERING

The forces that are driving the wheelset to steer in the way that it does originate from a number of different sources:

A. Wheelset conicity
B. Rolling radius and the curve radius
C. Co-efficient of friction
D. Bogie suspension
(Not discussed in this article)

A. WHEELSET CONICITY

Train wheels are designed to help steering around corners and in a simplistic sense are conical. When entering the curve the distance to be travelled is shorter on the low rail than the high rail. Initially the rolling radius is the same for both wheels, however, when entering a curve the leading wheelset shifts laterally, changing the rolling radius to match the difference in rail length. Eg. The high rail wheel having to travel further now has a larger radius than the low rail wheel which has to travel less distance. This change also generates angle of attack; the trailing wheelset attempts to align itself radially with the curve which further serves to increase angle of attack. In large radius curves, equilibrium is quickly achieved.

B. ROLLING RADIUS AND THE CURVE RADIUS

In sharp curves, the equilibrium is never achieved as the flange of the wheel comes into contact with the high rail limiting the rolling radius difference. **(See figure 10)**. As the equilibrium cannot be achieved, the effective radius of the wheel on the low (inner) rail at the point of contact is too large and the effective radius of the wheel on the high (outer) rail is too small.

As the wheels are rigidly joined they rotate at the same speed and the wheel on the low rail drives and the wheel on the high rail brakes. This increases the rolling radius difference and the wheelset develops an "anti-steering moment" forcing the flange into the high rail gauge face to a greater. Further miss-alignment of the trailing wheelset adds to the increased angle of attack and the increased lateral loading of the rail.

C. CO-EFFICIENT OF FRICTION AT THE WHEEL / RAIL INTERFACE

As earlier discussed **(see figure 1)** the normal co-efficient of friction on the rail head between a dry rail and rail wheel is in the range 0.5 - 0.65. Wet rail reduces the co-efficient to around 0.2. Grease reduces it further to below 0.15. The objective of the friction modifier is to maintain a co-efficient of friction in all weather conditions at 0.35 – experience has demonstrated that the friction modifier succeeds consistently in this regard.

EFFECT ON STEERING

When the rolling radius difference required for the wheelset to run in equilibrium is not achievable, then the angle of attack is generated as described above. The wheel flange limits the amount of rotation that can be achieved and as a result the wheel on the high rail sees a braking force as the rolling radius is too large for the speed of the vehicle. Conversely, the wheel on the low rail sees an accelerating force as the rolling radius is too large for the speed of the vehicle. As previously discussed, this coupled with the forces driving the trailing axle result in a high angle of attack and high lateral forces.

When the friction modifier is applied to the rail head it reduces the longitudinal and lateral forces and subsequently the anti-steering moment allowing the bogie to align closer to the optimum so reducing the angle of attack **(figure 11)**.

This reduction of the anti-steering moment allows the wheelset to move slightly towards the high rail as there is not the flange contact stopping the movement. The contact position of the wheel on the high rail is at a position of increased radius and similarly on the low rail the contact position is at a position of reduced radius. These combine to help the wheelset steer better, rotating the wheelset towards the low rail, reducing the angle of attack further. This is the effect that was seen at Barnt Green – the wheelset steers better and reducing / eliminating flange contact with the gauge corner of the rail.

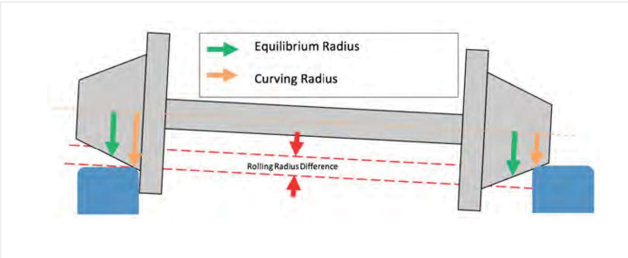

Figure 10: Rolling radius difference

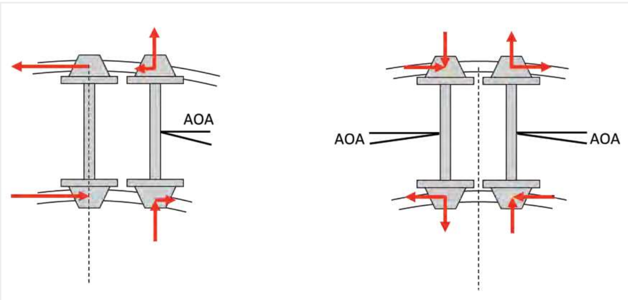

Figure 11: (Left) Tight radius curving, (Right) Reduced forces allowing for more radial alignment

POTENTIAL BENEFITS FOR THE WHOLE OF THE NETWORK

As Network Rail moves from CP5 to CP6, with a focus on efficiency, the use of friction modifiers could be of benefit to the wider network; Nuneaton is demonstrating savings of £12,000pa and Reading an estimated £100,000pa.

Examination of records has highlighted that there are significant numbers of premature switch failures on Network Rail infrastructure due to damage to the top of the switch rail (UIC defect code 504). These defects occur throughout the network. Given the numbers of defects it is unlikely that this issue is restricted to the newer design of switches such as RT60 / NR60. Switch blade damage occurs on all types of switch depending on the switch geometry and traffic carried. Currently around 67% of rail failures of switch blades are categorised under NR/L2/TRK/0053 as Hazard 4 (UIC code 504), 18% due Hazard 2 (UIC code 502) and 7% due to Hazard 1 (UIC code 501).

It is also recognised that international rail administrations also have similar defects in switch blades which would again indicate that this defect type is not restricted to RT60 / NR60 designs.

RECOMMENDATIONS

Engineers should not expect that switches will fail prematurely, repeatedly, in the normal course of events and an understanding of what failure modes they exhibit should provide an understanding of how the failures can be tackled. If the failure mode is due to damage to the switch blade (UIC code 504) or excessive sidewear of the switch blade or stock rail (UIC codes 501 and 502) then this may be prevented by reducing the angle of attack through the use of friction modifiers especially as part of a system with gauge face lubrication. Examination of defect records will reveal where the switches with frequent failures are located and these should be considered for treatment with friction modifiers.

As demonstrated at Barnt Green, curves that suffer from excessive sidewear may also be treated with friction modifiers so that the angle of attack is reduced and the contact force between the wheel flange and the rail is eliminated / reduced.

Currently it is not known whether friction modifiers should be installed at every switch having failures due to Hazards 1, 2 or 4. It is recommended that a site test is undertaken by a suitably experienced engineer prior to installing equipment to demonstrate that the friction modifiers work at that location. A single friction modifier system installation may be used to treat multiple switches in a station throat and in a ladder so the siting of the friction modifier equipment is very important as it will determine which switches are treated effectively. Additionally, consideration must be given to the practical implications of the installation; can it be maintained safely and easily; can it be filled without track access issues? The analysis of the failure data should allow a prioritised list of switches to be tested to see if the installation of friction modifiers would be beneficial. This would also help to generate a cost benefit analysis that would demonstrate the payback period for each set of equipment to be installed.

There are friction modifier systems installed elsewhere as noise reduction systems - for example there are a number of units in Euston Station throat area. There are no differences in the systems in terms of equipment or application rate for noise reduction and switch protection and an analysis of the failure rates for the switches that are treated by the friction modifiers would allow greater understanding of the effect that the reduced angle of attack at those locations and may lead to the repositioning of the equipment to maximise the benefits to switch life, whilst maintaining the noise control benefits.

There is also scope for analysis of the benefits of this technique to address side wear in plain line sites where it is shown that the rate of side wear is unacceptable and leads to premature rerailing even when the gauge face lubrication systems are installed and working correctly.

CONCLUSION

It has been demonstrated that the friction modifier system can give a significant improvement in the life of switches. It is expected that the improvement would be at least 650% as demonstrated at Nuneaton. This is achieved by reducing the angle of attack between the wheel and the rail through the switch such that the contact forces are greatly reduced or eliminated entirely.

REFERENCES

[1] Thameslink Programme report dated 4 March 2009.

[2] Network Rail Standard: NR/L2/TRK/0053 ISSUE 5 - Inspection & repair to reduce the risk of derailment at switches (nr/sp/trk/053).

TECHNICAL