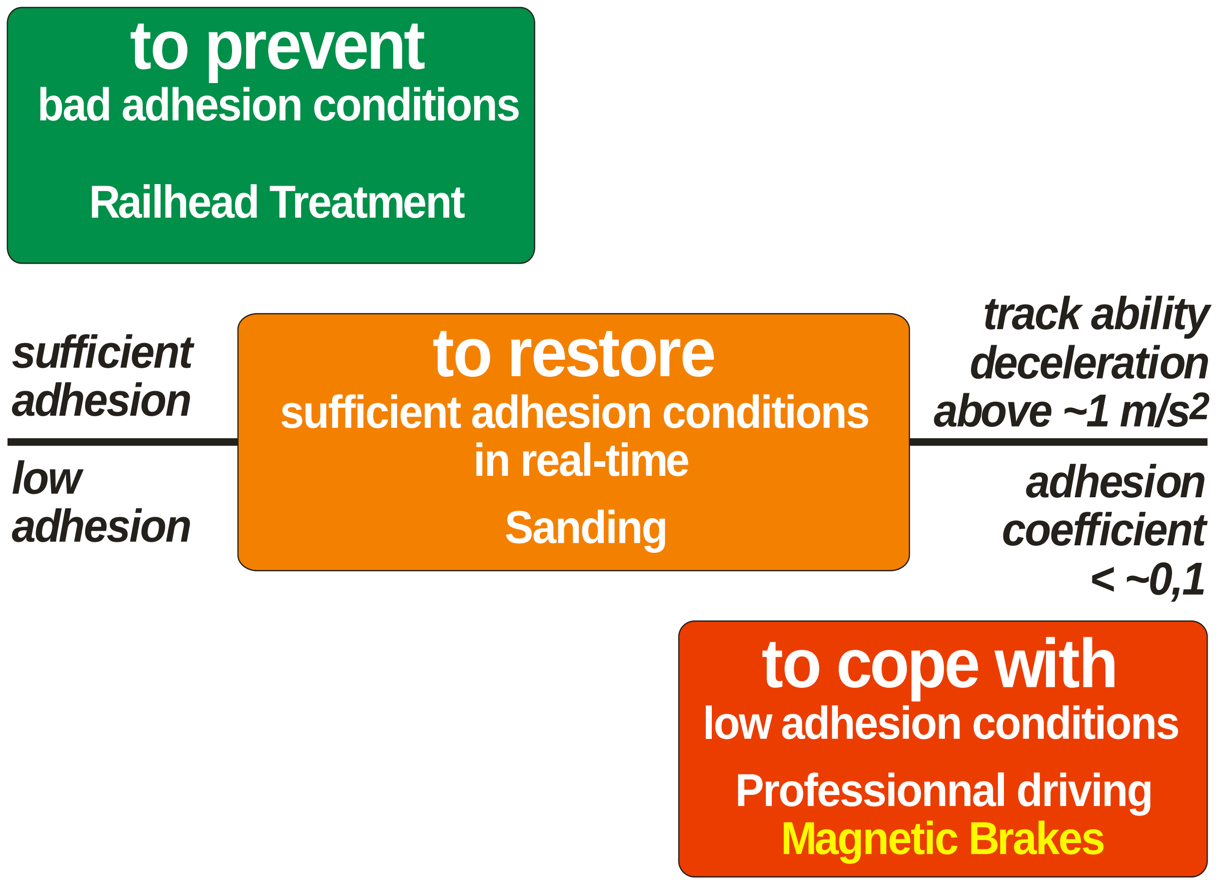

Magnetic Brakes to avoid SPADs due to poor adhesion conditions

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Abstract

To operate a classical wheel-rail system, the steel wheels must be able to transmit a longitudinal traction force tangential to steel rails in the direction of motion and a braking force in the opposite direction. Adhesion is the phenomenon that allows this action. The maximal tangential force that can be transmitted by a wheel to a rail is approximately equal to the vertical force acting on the wheel multiplied by the adhesion coefficient. This coefficient is significantly lower than the tyre-asphalt coefficient on dry roads, and its value decreases with speed. Its typical values are between 0.35 at low speed and 0.10 at very high speed. Moreover, this coefficient can come close zero in bad weather conditions, especially in autumn because fallen leaves lubricate wheels and rails. In these situations, trains are susceptible to slipping during acceleration or sliding during braking.

Namely in North European countries, many Signal Passed At Danger (SPAD) events occur each year, due to low adhesion. After the year 2005, which was particularly bad for this kind of SPADs, the Rail Accident Investigation Branch (RAIB) of the United Kingdom sent a lot of recommendations to Train Operating Companies and launched some studies on this topic.

The paper presents the different means to deal with low adhesion conditions: rail-head treatments, sanding and professional driving. Finally, it describes solutions using additional brake systems to avoid low adhesion induced SPADs, and concludes that the use of track brakes for passenger trains is a convenient solution to fight against low adhesion induced SPADs.

Keywords

Signal Passed At Danger (SPAD), adhesion, magnetic track brakes

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1. Introduction

In North European countries, many Signal Passed At Danger (SPAD) events occur each year. Some are due to the inattention of the driver or due to human errors acting on the configuration of the brake equipment of trains. Some others causes do not involved human being or rolling stock but adhesion conditions exceptionally low between wheels and rails.

Adhesion between a dry steel wheel and a dry steel rail is normally not very high. Wet conditions are also considered as normal and the adhesion coefficient allows decelerations of 1 m/s2 or above. Such conditions are usual. However, especially in autumn, rails can be polluted by leaves and others stuff that can lead to a lost of adhesion and an inevitable overrun of a station or, even worse, to a SPAD.

After a short presentation of adhesion, the paper presents the different means to deal with low adhesion conditions: prevention of poor adhesion conditions (vegetation clearance, rail-head treatments), restoration in real-time of adhesion (sanding), and coping with very poor adhesion conditions (information and professional driving, brakes independent of adhesion).

2. Adhesion

Adhesion is the phenomenon that allows the transmission of efforts between wheels of trains and rails. The maximal tangential force F_w that can be transmitted from a wheel to a rail is approximately equal to the vertical force acting on the wheel W_w multiplied by the adhesion coefficient f_w.

This coefficient f_w is significantly lower than the tyre-asphalt coefficient on dry roads, and its value decreases with speed. Its typical values are between 0.35 at low speed and 0.10 at very high speed

2.1 Slipping and sliding

<table>
<tr><th></th><th>risk of delays</th><th>risk for safety</th><th>maintenance</th></tr>
<tr><td>slipping</td><td>difficulty to accelerate
difficulty to maintain the speed on gradients</td><td>no</td><td rowspan="2">rail head tear

more wear
(wheel and rail)

flat wheel</td></tr>
<tr><td>sliding</td><td>preventive speed reduction
lower rate of deceleration
station overrun leading to difficulties for passenger transfers</td><td>SPAD
Buffer collision</td></tr>
</table>

Trains have difficulties to accelerate or to maintain authorized speeds on gradients in case of bad adhesion conditions. The worse case of slipping is when speed is null and all driving wheels are revolved transmitting rather no efforts on rails. Strong rail tears are feared and time delays increase drastically. However, running safety is guarantied. Wheelslide Protection Systems (WSP) during traction stages can prevent harmful wear of rails.

Opposite to slipping, sliding is more critical for safety. If no preventive speed reduction is done bad adhesion conditions can lead to station overruns and even to signals passed at danger (SPADs). For shunting moves, low adhesion on dead-end shunting tracks can lead to collisions with buffers. Wheelslide Protection Systems (WSP) during braking stages can prevent harmful wear of wheels, but has practically no reduction effect on overruns and SPADs.

2.2 Main factors leading to poor adhesion

Overruns and SPADs statistic shows clearly such events happen very more frequently in autumn (cf. **figure 1**).

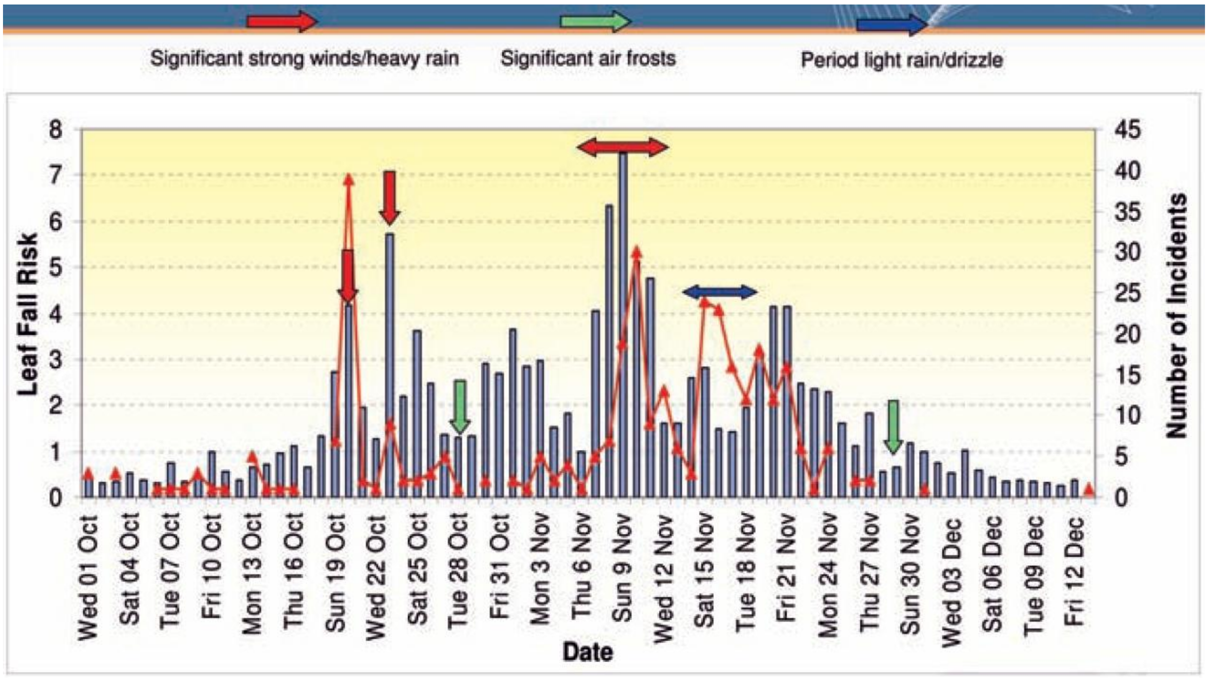

Figure 1: Correlation between Leaf Fall Risk and Bad Adhesion Incidents [AWG, Issue 24, 2009]

Leaf contaminated railhead is the very first reason of poor adhesion condition, as grinded dead leafs act as a perfect sticky grease stuck on rail heads. Some others weather conditions are also often named: frost, black ice, dirty dampness.

Some areas have poor adhesion conditions along the whole year. This is due to air pollutants in large conurbations and salt sprays at costal locations. A UK wide survey concludes 24.3% of overruns didn't occur on a damp or leaf contaminated railhead [AWG, Issue 23, 2008]. Driver mistakes are responsible for a lot of them but they let place for poor adhesion due to "pollutant", too.

2.3 Low Adhesion between the Wheel and the Rail - Managing the Risk

In 2009, the Rail Safety and Standard Board of the UK (RSSB) publishes the first issue of a guidance instrument concerning the management of the low adhesion risk [RSSB, 2009-GN8540]. This document gives guidance on interpreting the requirements of the Railway Group Standard GE/RT8040, which is mandatory [RGS, 2009-RT8040].

Both these documents focus on local treatment at specifics sites. Train borne equipment documents are discussed only in relation with specific sites that are not enough protected by prevent actions.

In others words, legislation, technical and financial efforts are mainly related to the prevention of bad adhesion conditions (cf. **chapter 3**). In spite of this highly absorbent topic, some recent efforts were made to ameliorate the restoration of adhesion in real-time (cf. **chapter 4**). Coping with low adhesion conditions is almost not mentioned, or only in relation with mutual information exchanges between IM and RU and defensive driving (cf. **chapter 5**).

3. Prevention of poor adhesion sectors

Not only the abundant literature but also many action plans concern prevention of poor adhesion conditions. Main difficulties encountered to build cost-effective plans are:

- what percentage of the network has to be considered as low adhesion site ?
- when and how long a site has to be considered critical about adhesion along the year ? (cf. **figure 2**)
- how many time a week have rail-heads to be scanned/treated ?

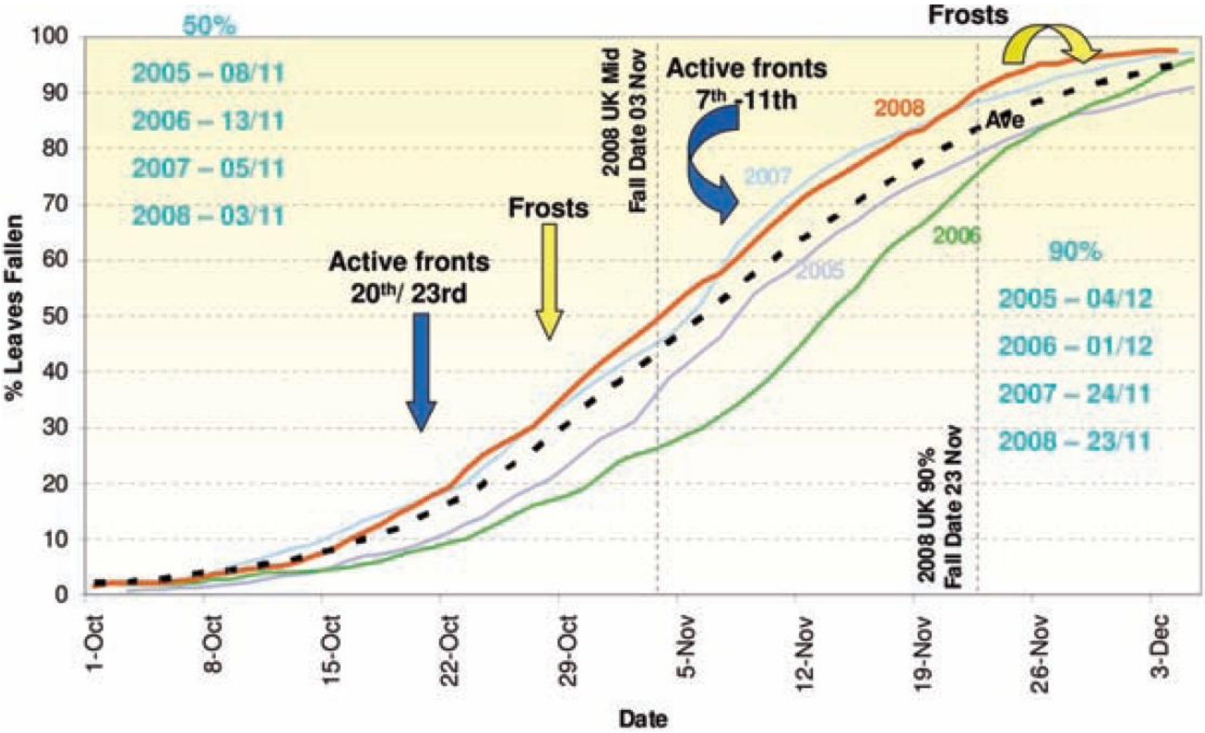

Figure 2: UK global variations in percentage of Leaves Fallen [AWG, Issue 24, 2009]

3.1 Vegetation clearance

First action to prevent dead leaf deposit is the vegetation clearance. Another action is to build safety nets to protect the track from leafs. Short distances between trees and tracks bring rapidly limits to such actions.

3.2 Rail-head treatment

Certainly the most costly and frequent action against low adherence conditions is the rail-head treatment. During autumn many water jetting and Sandite application trains permanently run on the specific sites. Scrubbing devices and hand sanding are also used. New ways of cleaning are also studied, like microwave superheated water/steam device follows by air jets. One have to be cautious with Sandite as it is - with sand - one of the major causes of Wrong Side Track Circuit Failures (WSTCF - cf. §.4.2).

What was particularly discouraging was a SPAD incident just after a rail-head treatment. In 2007, the Signal LW9 was Passed at Danger at Lewes only 9 hours after a rail-head treatment [RAIB, 2007-25(2)].

4. Restoration of the adhesion

4.1 Sanding

Sanding is a very old mean used to ameliorate adhesion. Almost all traction units have sanders that can be used either to allow higher tractive effort to be transmitted or higher braking effort between wheels and rails.

The dispersion of sand discharge rates is quite high (cf. **figure 3**). A comparison of six systems from different suppliers was made. Each of the four main suppliers has a high dispersion rate for its own. Another supplier has a mean value near only 0.5 kg/min. The RGS recommendation is to use a much higher discharge rate than today (2 kg/min), what was seldom reach by sanders, today.

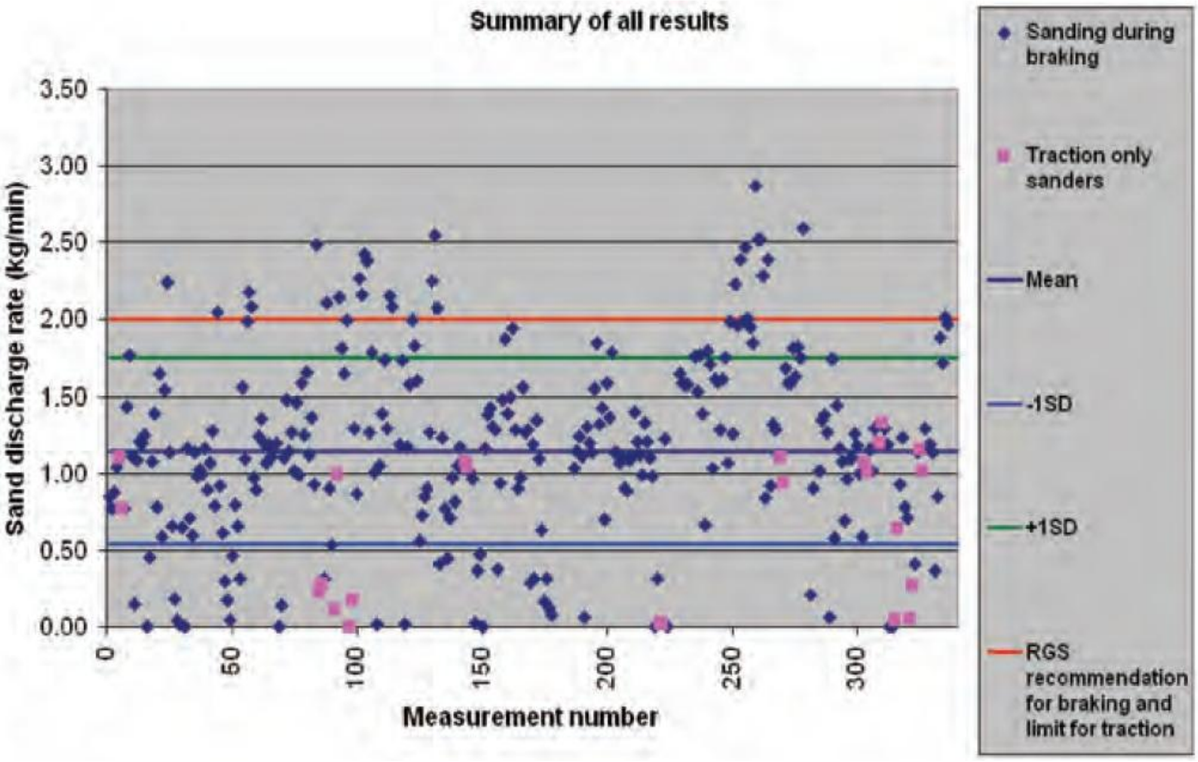

Figure 3: Dispersion of sand discharge rate (kg/min) [AWG, Issue 25, 2010]

It's seems reasonable to use sanders independently of the tractive or braking effort, at least for breaking. As soon as the WSP system detected sliding on more than one axle, sand should be released. So, adhesion has more opportunity to be restored enough for lighter braking.

What is actually confusing for the driver is the illumination of the "sanding" yellow light to indicate a WSP action even if no sand was discharged. One solution is to have two lights, one for the WSP system and another for the sanding. What is more important is to allow drivers to act "directly" sanders if such action is not automatically done.

With this new opportunity, drivers who brake "lighter and earlier" could dispense sand as soon as the "WSP" yellow light lit, without increasing the selected braking effort.

4.2 Sand, disk brakes and track circuit failure

Sandite applications and sand can lead to create a non-conductive layer between wheel and rail. This effect increases the risk of failure to detect the concerned train and any subsequent trains. In such a case, the risk of propagating delays is very high and a lot of signals, normally cleared long before arrivals of trains will indicated restrictive or danger aspects. So, sand leading to WTSCFs could contribute to more SPADs !

4.3 Tread braked stock and number of braking axles

Tread brakes instead of disk brakes have a scrubbing effect on wheels and help to restore better adhesion between wheel and rail.

A high number of braking axles has also a restoring effect on adhesion. The first axles of the train have a little scrubbing effect on the rail-head so the following braking axles find better adhesion conditions. However, the **figure 4** should be interpreted carefully. Short trains stop frequently and stop trains have frequent accelerations and braking stages that are time consuming in case of low adhesion condition. Moreover, sand discharges from short train lead more frequently to WSTCFs.

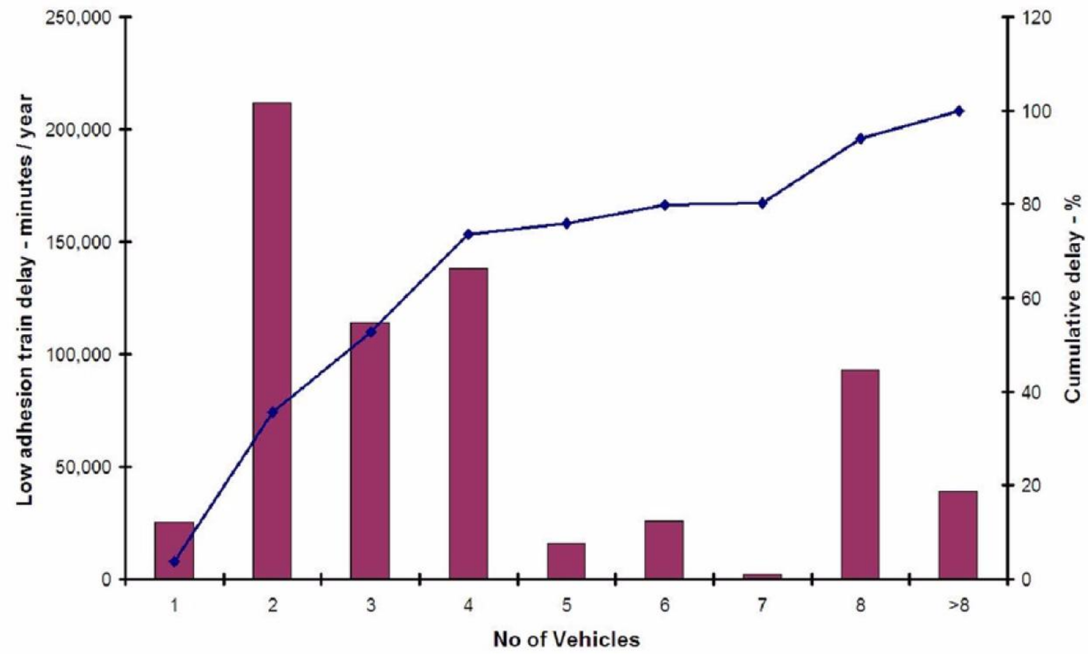

Figure 4: Delays due to low adhesion conditions versus number of vehicles by train [RSSB, 2008]

5. Coping with poor adhesion

Coping with low adhesion is probably the best thing to do. At very high speed, adhesion is low and the huge necessary tractive effort to reach and to maintain the ceiling speed has to be shared on many axles. For braking, the situation seems better, as all axles participate normally to decelerate the train. However, for very bad adhesion condition the transmission of the braking effort to rail is critical.

5.1 Defensive driving techniques

The general rule for drivers is to adopt defensive driving techniques. Surprisingly, in its "Guidance Note Defensive Driving Techniques", the Association of Train Operating Companies (ATOC) proposes only one action to drivers. They "*should be advised to brake earlier and lighter*" [ATOC, 2003-GN007]. ATOC does not mention sanding or application of precautionary speed reduction.

"Braking earlier and lighter" is the technique to be followed in case of low adhesion conditions. Such a braking technique is good but not always sufficient (cf. **table 1**). Furthermore, this technique is not correctly taught by the Adhesion Working Group (AWG) (cf. **figure 5**).

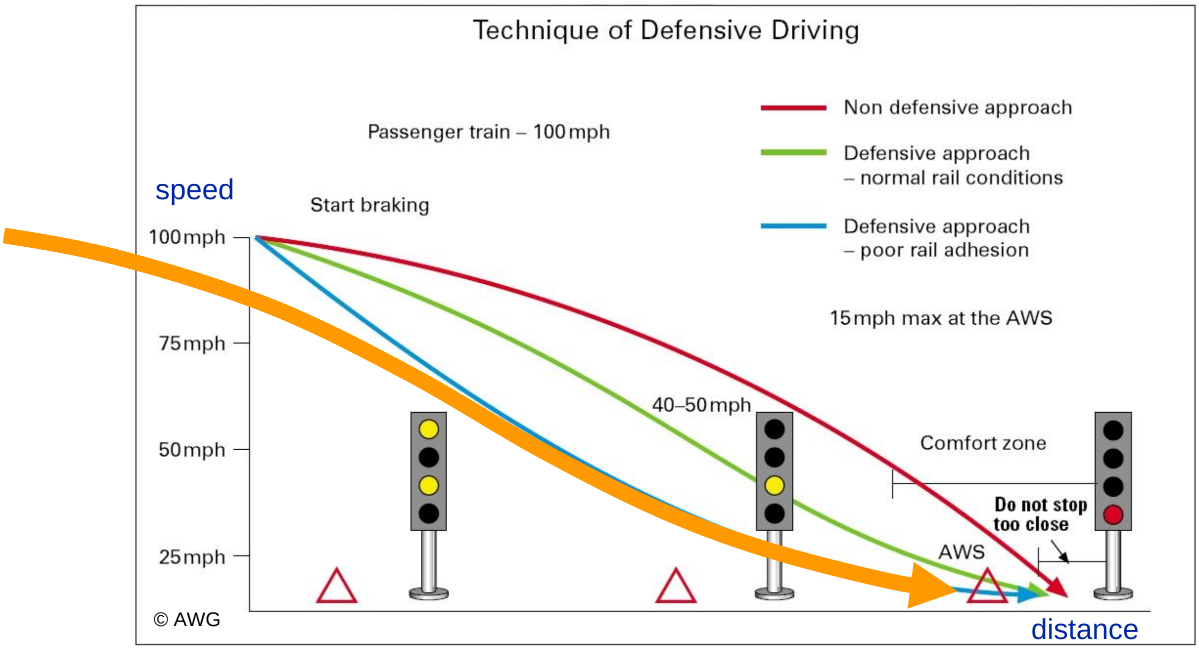

Figure 5: Bad defensive approach is case of poor rail condition (lowest thin curve in blue) [AWG, 2006-2010]
[the thick orange arrow was added to the figure to show the correct
defensive approach in case of low adhesion condition]

Application of brake in the "Step 1" position "light braking" produces normally a deceleration of 0.3 m/s2. Such deceleration is not obtained if the adhesion level is under 0.03. Such a low adhesion levels was observed in almost all SPAD situations inventoried in **table 1**. Unfortunately, even if the WSP system is in action, no sanding is provided for such a low braking effort. For some Electric Multiple Units (EMUs), equipped with "stepless" brake controller, sand was dispensed only if the selected braking effort is higher than 40% of the full braking effort. Some sander actions are cut-off under 30 kph, and some sanders stop the sand discharge automatically after a certain time.

Some of these limitative parameters on automatic devices are understandable as sand can lead to create a non-conductive layer between wheel and rail and so can increase the risk of failure to detect the train applying the sand and any subsequent train (cf. WSTCFs - §.4.2). Therefore it is right to have variable rate automatic sanders coupled with speed. However, stopping sanding after a certain time is questionable. In any case, manual sanding should be available any time.

Normally, systems have to be designed so that sand is discharged on rail-head as soon as WSP system intervenes on more than one axle during a braking stage, independently of the speed. It is well known that, after the analysis of the Escher incident, sanding in lower brake steps would have lower significantly the speed of the faulty train and, perhaps, even prevent the SPAD (cf. [RAIB, 2007-25(1)]).

What is confusing for the driver is the illumination of the "sanding" yellow light to indicate a WSP action even if no sand was dispensed. One solution is to have two lights, one for the WSP system and another for the sanding.

With this new information, drivers who brake "lighter and earlier" could dispense sand as soon as the "WSP" yellow light lit, without increasing the selected braking effort (cf. §.4.1).

"Braking earlier and lighter" is good for safety but bring delays. One way to reduce the stress of drivers, who are torn between caution and punctuality, is perhaps to plan an "autumn timetable" with arranged running times.

5.2 Low adhesion section sight

Known sections of line where poor adhesion can be expected are equipped with at both sides by signs, successively "poor adhesion site ahead" and "end of poor adhesion site". Surprisingly, the "poor adhesion site ahead" sign is not only a warning sign, but it exempts drivers to inform others that they encounter small problems due to low adhesion. However, repetitive information about small adhesion problems is very efficient to act really carefully avoid SPADs. For example, if two drivers announce successively bad adhesion condition, it could be a good idea to order a lower ceiling speed or to clear signal in front of next trains to reduce the risk of SPADs.

One other weakness of such signalling is the "end of poor adhesion site" sign. This indication gives the false impression that we enter on a "good adhesion site" what is perhaps not the case: border between low and good adhesion sites does not obey to signs!

5.3 Learning from reality

Some overruns and SPADs were analysed thanks to the information contained in the train "black box". Value of deceleration is, in each examined cases, 5 to 10 times lower than the normal low adherence coefficient (0.15). Even with an earlier and lighter braking, drivers can hardly stop their train with a so low adhesion coefficient.

Therefore, it is pertinent to explore the use of brakes that are independent of adhesion.

		Speed Range [km/h]			
References	Train	0-20	20-60	60-100	> 100
[EBA, 2008]	S25066	---	0.050	0.020	---
[RAIB, 2007-25(1)]	1A12	---			0.025
[RAIB, 2007-25(2)]	2D45	---		< 0.010	0.020
[RAIB, 2007-25(3)]	2N50	0.025			---
	1E69	0.035			
	1R73	0.020		---	
	2J75	0.015			---

Table 1: Lowest average adhesion levels having led to a station overrun or a SPAD

5.4 Brakes independent of adhesion

Two very different magnetic brakes families can act efficiently to slow down a train independently of adhesion conditions.

5.4.1 Eddy Current Brake (ECB)

Eddy-Current Brake (ECB) does not interact directly with rails but has an air gap of about 6 mm. A high magnetic field is generated in the brake device and the magnetic circuit closed itself through the air gap, the rail, and the air gap again. The speed and the induction field produce electric currents, called Eddy-currents. Electrical laws indicate that an attractive force is produced between the brake device and the rail and, simultaneously, a retardation force.

ECB can produce a longitudinal retardation of more than 0.4 m/s2 at high speed. Nevertheless, this value drops drastically at low speed according to electrical laws. Simultaneously high attractive forces appear at low speed (cf. **figure 6**). Such forces have to be avoided for mechanical reasons and ECB have to be cut-off at approximately 50-60 km/h.

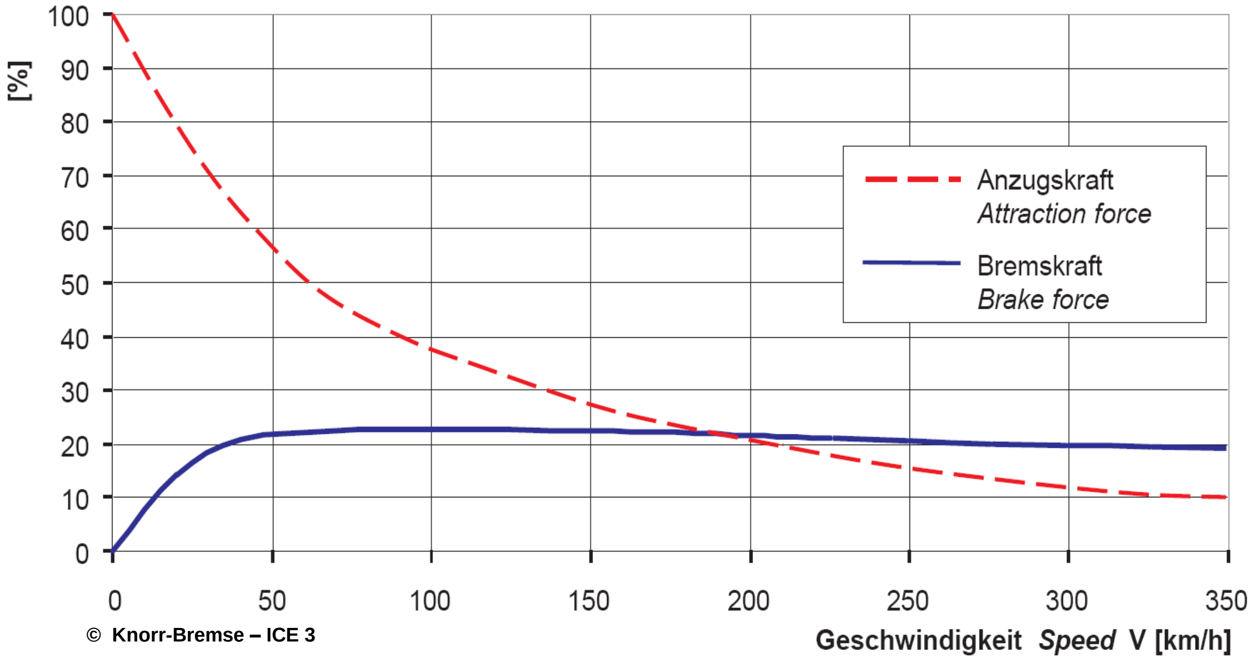

Figure 6: Attraction and brake forces versus speed of the Eddy-current brake of the German train set ICE-3

Therefore, ECBs are not appropriate for braking trains running at medium and low speed. One other disadvantage of this kind of brakes is their considerable weight relative to the relatively light weight of EMUs. Finally their main disadvantage is their competition with Magnetic Track Brakes (MTB) to be put at the same place between the axles of the bogie (cf. **figure 7**).

5.4.2 Magnetic Track Brake (MTB/EMB/Mg)

Magnetic Track Brakes (MTB) interact directly with rail-heads. Although MTB produce attractive forces between wheels and rails, the retardation force is only produced by mechanical scrubbing. Therefore such brakes are not totally independent of the adhesion conditions. However, surfaces in contact are much bigger and relative movements are translations only. So, the coefficient of brake force is high at low speed even with bad adhesion conditions (cf. **figure 7**).

Maximal force applied by MTB is about 80 kN per unit. Considering a weight of 18 t per axle, the maxim retardation can be about 0.35 m/s^2 at 150 km/h and greater than 0.60 m/s^2 under 50 km/h. For EMUs totally equipped with MTB, almost all SPADs described in **table 1** would have been avoided.

The main default of MTBs is the considerable wear of both brakes and track. Therefore, they have to be applied at their maximum power only in very critical situations.

Magnetic track brakes should be automatically applied in a braking stage if the WSP system and sanders are already active for a certain time and the brake controller is in the emergency brake position. Effort on the rail should be automatically set according to the speed of the train.

Under a certain speed, magnetic track brakes with full effort are applied if the brake controller is the emergency position, independently of other criteria.

Under a certain speed drivers should have the possibility to use directly magnetic track brakes if the WSP is active in a braking stage, independently of the position of the brake controller.

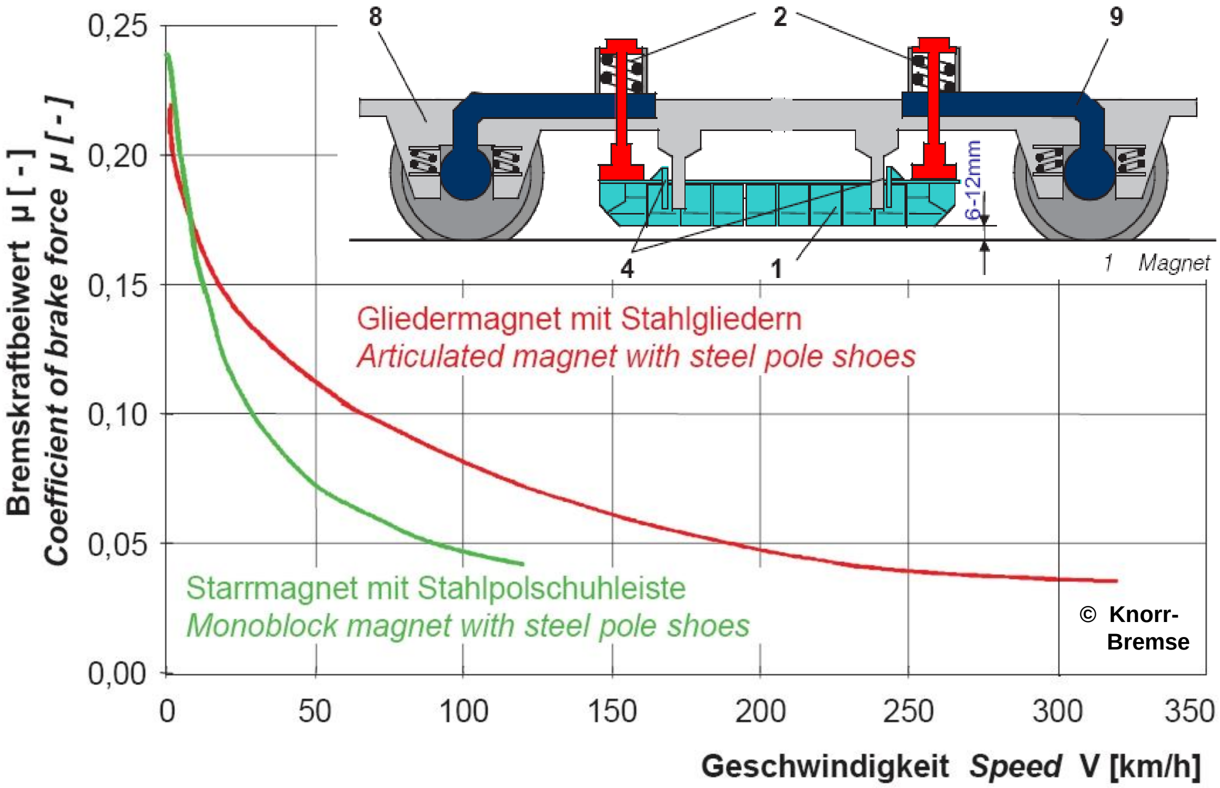

Figure 7: Brake coefficient versus speed for standard Magnetic Track Brakes (MTBs)

6. Conclusion

Adhesion sectors are very difficult to determine. Especially in autumn, it is quite impossible to affirm a site is not a low adhesion site. So, full prevention in space and time of low adhesion on the whole network - and even for specific sites - would be too much expensive.

Indication of a well-known low adhesion site by a sign is understandable, but should not exempt divers from informing signalmen each time low adhesion makes braking distances longer.

Coupling of sanders with WSP devices and, if necessary, with brake controller has to be more studied. Information given to driver on WSP and sanders actions has to be developed. At any time, drivers should have the possibility to start sand discharge up. Drivers have to be taught about defensive driving techniques using sanders simultaneously with the brake controller on the "step 1" position.

New rolling stock should be equipped with magnetic track brakes, in particular for short trains. Action and power of such brakes have to be controlled in close coordination with the WSP controller, the speedometer and the emergency brake position.

To conclude, magnetic track brakes offer a suitable solution to reduce drastically overruns and SPADs due to poor adhesion conditions.

7. Acronyms & Bibliography

ATOC	Association of Train Operating Companies
AWG	Adhesion Working Group
ECB	Eddy-Current Brakes
EMU	Electric Multiple Unit
EPFL	École Polytechnique Fédérale de Lausanne
LITEP	Laboratoire d'Intermodalité des Transports et de Planification
MTB	Magnetic Track Brake
RAIB	Rail Accident Investigation Branch
RGS	Railway Group Standard
RSSB	Rail Safety and Standard Board
SPAD	Signal Passed At Danger
STRC	Swiss Transport Research Conference
UK	United Kingdom
WSP	Wheelslide Protection System
WSTCF	Wrong Side Track Circuit Failure

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