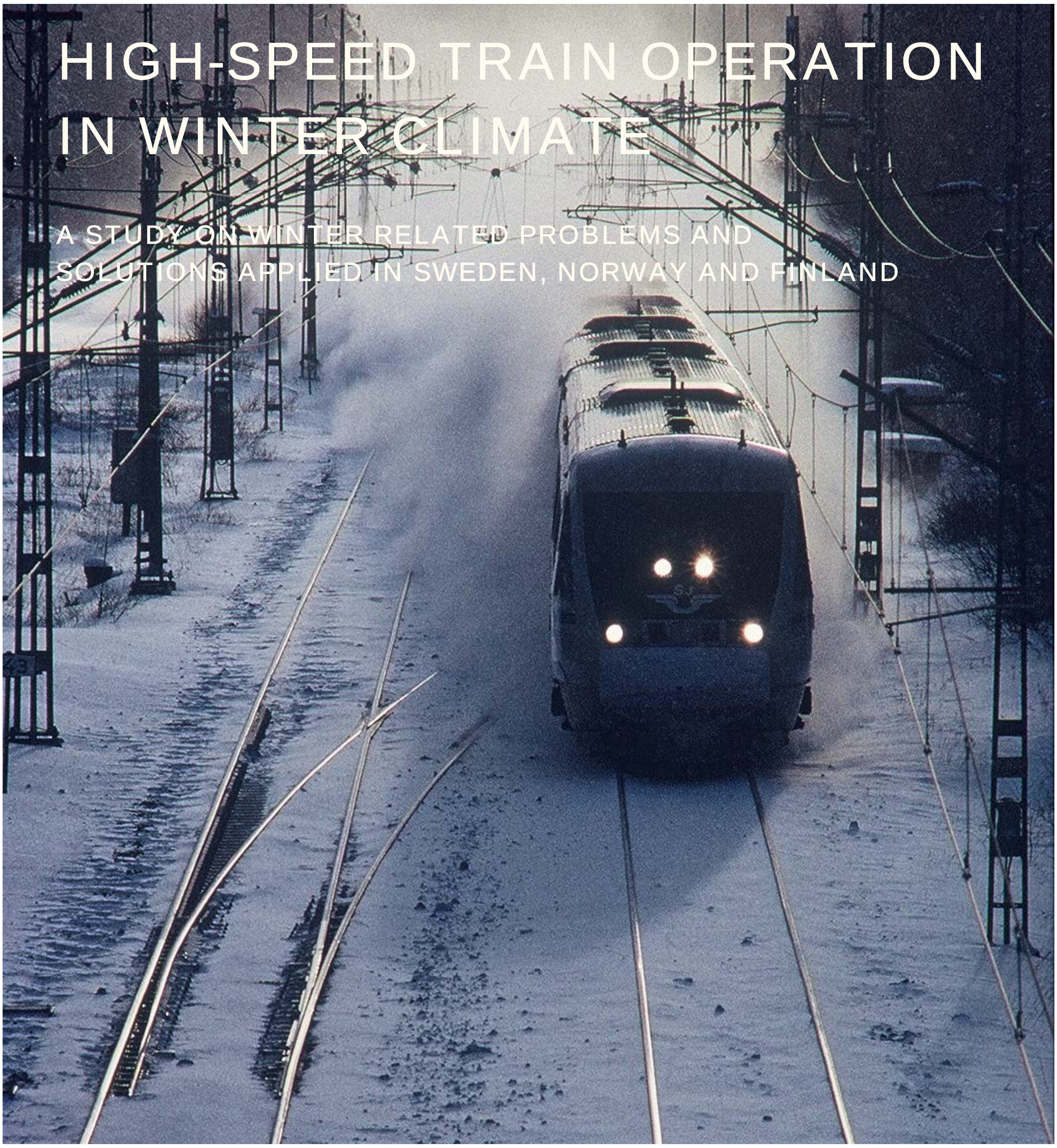
transrail

grönatåget

HIGH-SPEED TRAIN OPERATION IN WINTER CLIMATE

A STUDY ON WINTER RELATED PROBLEMS AND SOLUTIONS APPLIED IN SWEDEN, NORWAY AND FINLAND



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PREFACE

This is a study of the winter problems regarding high-speed passenger train services in the Nordic European region. The investigation has been performed within the Swedish National Rail Administration's (Banverket) research project Gröna tåget.

The outcome of this investigation has been much dependent on the interviewed persons and their shared experiences. We believe that we for the assignment have been able to engage as well representative as competent interview persons. The persons included have different backgrounds but act in the railway sector.

All interview persons have received us very well and have made contributions from different perspectives that have been of great value for our work. We would like to thank all interviewed persons who through their participation have made this study possible. A special thank to the Swedish National Rail Administration for financially supporting this study.

ABSTRACT

During winters the train services in Scandinavia – in one way or another and to various extents – are struck by constantly recurring problems related to snow, ice and coldness. If a winter is harsh and the circumstances are unfavourable the problems that arise can result in severe consequences for train operations and economy. In spite of the winter's impact on train operations in the Nordic region, there is a shortage of assembled knowledge on winter problems.

The main purpose of this limited investigation is to compile the knowledges and experiences regarding primarily the Scandinavian high-speed passenger services in winter climate – the affects of snow, ice and coldness concerning both infrastructure and rolling stock. In order to fulfil this aim both a literature study and qualitative research interviews have been carried out with representatives of the Nordic railway sector.

From this investigation the overall conclusion is that winter is unfortunately not an issue of high priority the year around. This conclusion can amongst others be drawn from the too often acute and short-term solutions and measures applied to deal with the problems that arise.

The study identifies that;

- there are still unsolved winter problems such as difficulties with switches, brakes, ballast pick-up etc.,
- many problems are more or less independent of the train speeds, other are expected to increase when speeds are increased,
- there is a lack of experiences and knowledge of high-speed operation (above approximately 200 km/h) in winter climate, as found in Scandinavia.

On the basis of this limited study, we propose a further study in order to ensure that high-speed train services (above 200 km/h) can be operated with a minimum of problems due to winter conditions. This would involve a study of winter aspects and development actions with focus on;

- Speeds above 200 km/h. The most severe problems being judged as:
    - ballast pick-up,
    - disc brakes,
    - running dynamics,
    - current collection,
    - platform tracks,
    - collisions with large animals.
- Standardisation, authority requirements and verification of rolling stock and infrastructure.
- Guidelines for rolling stock and infrastructure design and purchases.
- Recommendations for management of high-speed train operations in winter conditions.

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1 INTRODUCTION

1.1 BACKGROUND

This study is part of the R&D program Gröna tåget (“the Green train”) that, as regards winter aspects, aims to:

- strengthen the ability to procure and design the next generation high-speed passenger trains and infrastructure in Sweden,
- influence the all-European standardisation of rolling stock and infrastructure.

Despite the large influence on train operations due to winter problems there is a lack of compiled knowledge in Sweden today. That is why there has been a need for a project that gathers existing winter experiences and knowledge from a Nordic perspective, something this limited investigation tries to fill.

From a Scandinavian point of view studies of this kind are of importance as most manufactures and deliveries of rolling stock and railway equipment are concentrated to countries where the climate conditions are different from ours.

Outside Scandinavia winter problems are sometimes met in other ways. The service speeds may be reduced a few problematic days in the year. Trains may sometimes even be cancelled.

In Scandinavia the train services are expected to be unaffected during a fairly long winter time, except in the most severe situations. This results in higher requirements as regards design, operation and maintenance. This investigation looks into these demands from both a rolling stock and an infrastructure perspective for the Scandinavian high-speed services.

1.2 PURPOSE AND QUESTIONS AT ISSUE

The general aim of this study is to collect and compile knowledge and experiences concerning passenger train services in winter climate, with the primarily interest in winter experiences from systems operated at high speeds. With this purpose and with aspects on rolling stock, infrastructure, operation and maintenance the investigation focuses on following central issues:

- the difference between high-speed train services and conventional passenger services during winter,
- the worst winter scenario from a weather point of view,
- the most common and the worst winter problems,
- the winter problems that get worse with the increase of speed,
- the solutions applied – both successful and unsuccessful and
- areas and solutions that ought to be examined or investigated further.

Together this is believed to give a collected picture of winter high-speed train services in Scandinavia including problems and possibly also solutions.

1.3 METHOD

The investigation has been performed with a literature study at first and a following qualitative interview survey. Throughout the literature study the problem area got further defined and a basis for the interviews was developed. A total of 19 interviews have been held with 35 representatives from different parties within the railway sector in Finland, Norway and Sweden.

In the study all reported problems, as well as proposed measures against the problems, have been listed. The report forms a summary and checklist of winter problems, more ore less irrespective of speed. Based on the list, the problems judged to increase at higher speeds have been pointed out in specific.

1.4 DELIMITATIONS

The following delimitations have been made throughout in this study:

- Neither freight trains nor diesel vehicles are included.
- Little consideration is taken to older rolling stock and well known measures – applied designs and techniques etc. – taken against winter. Focus of attention is on modern rolling stock.
- The efficiency, cost and possibility to implement the presented measures against winter problems have not been evaluated.

1.5 DEFINITIONS

This study assumes the following definitions:

High-speed	Speeds from 200 km/h and above.
Winter problem	A problem regarding rolling stock, infrastructure, operation or maintenance that is due to winter.
High-speed dependent winter problem	A winter problem that either: • gets worse with the increase of speed, • is only found in high speed-train services or • causes increased problems to a high-speed train service e.g. speed restrictions.
Snow smoke	Dry snow that whirls around a running train.
Ballast pick-up	Macadam stones that are lifted from the ballast as a consequence of train passage.

1.6 HIGH-SPEED ISSUES OF SIGNIFICANT IMPORTANCE

Out of all the problem areas that this study discusses, some winter issues are considered to be of significant importance from a high-speed perspective. These are winter problems that are expected to get worse with the increase of speed;

- Running dynamics, chapter 2.3.4
- Disc brakes, chapter 2.4.1
- Collisions with animals, chapter 2.6
- Pantograph, chapter 2.9
- Platform tracks, chapter 3,5
- Ballast pick-up, chapter 3.7

2 ROLLING STOCK

The winter climate conditions require thorough considerations on the various rolling stock design aspects. For instance, all equipment must be very robust in order to cope with the large ice build-ups that can weigh up to several hundred kilograms. This concerns for instance cables, pipes and other more sensitive equipment that is exposed to snow, melting water etc.

In the sections below identified rolling stock high-speed dependent winter problems are described. The first of the following chapters deals with the worst climate conditions from a rolling stock perspective. Subsequently, problems related to specific rolling stock areas are discussed.

2.1 WORST WEATHER CONDITION

The countries studied have different climate conditions that make it hard to come to a general conclusion concerning the worst weather condition for rolling stock. The combinations of snow, temperature, wind etc make the conditions differ from one region to another. During a run a train may be subject to varying climate conditions, from coldness and dry snow to temperatures above zero centigrade. Furthermore, the various rolling stock designs react different to the various kinds of weather and are in some situations more sensitive than others.

Regarding what kind of weather that causes most problems from a rolling stock perspective, two different scenarios have been pointed out as particularly unfavourable. The first one is the occurrence of dry snow. This type of snow is light and consists of very fine particles that whirls around the train while in motion, as seen in figure 1, and easily cling to the train. Dry snow builds up in areas such as the bogie, pushes inside the vehicle through e.g. air intakes and also affects disc brakes.

Figure 1. Snow smoke from the Swedish X2 trainset. Although the track seems more or less free from snow, the train is surrounded by a cloud of snow.

The other harsh weather condition regards temperature changes – the crossing of the point zero degrees Celsius – which can be most devastating when it concerns ice accretion on the vehicles. Ice can build up on trains as the trainborne snow melts and then freezes. This procedure takes place as a train carrying snow enters a warmer region or when a train has stopped and the generated heat from e.g. the brakes cause the snow to melt. The problems with ice then occur as the train again faces cold surrounding with degrees below zero. In figure 2 there is an example of a bogie covered with ice.

Figure 2. An example of a bogie with adhering ice.

Changes in climate also create condense and damp on the rolling stock which e.g. can have an impact on traction equipment. Long tunnels can for instance hold temperatures up to +10 ºC while the temperature outside reaches -20 ºC. A specific case for the Nordic countries regarding humidity is even specified in the high-speed rolling stock Technical Specification for Interoperability (TSI). The TSI states that the sudden changes of the air temperature local to the train shall be considered for a maximum variation of 60 ºC[1].

There are of course other weather situations that in some specific cases can cause worse effects. Just coldness or strong wind alone is not a big problem but in combination with other winter climate conditions the case can get much worse.

2.2 SNOW PACKING

Snow packing occurs mainly in the bogies and the underframe. It will affect both the bogie movements and the movements within the bogie as well as the components placed underneath the floor of the carbody. A snow filled bogie is shown in figure 3. The problems in conjunction with packed snow and ice are related to blocked movements, squeezed and damaged components and reduced accessibility for maintenance.

[1] Lerouge, B & Alibert, B (2005). *Draft Revised HS RST TSI (main text)*. Brussels: AEIF 22.12.2005.

Figure 3. Snow packing in a bogie.

Through site investigations in Japan it has been shown that snow and ice build up very fast under the vehicle floor when the daily average temperature gets around -4ºC and the daily snowfall exceeds 3 cm. This is described in figure 4 below were the amount of accreted snow and ice masses have been set into four levels: A<B<C<D.

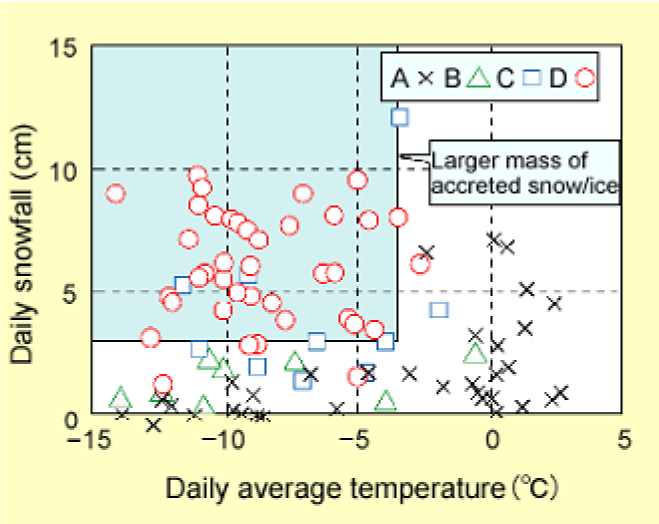

Figure 4. Relationship between amount of accreted snow and ice and daily average temperature[2].

During these conditions the density of a mass of an accreted snow and ice came to stretch between 150 – 900 kg/m^3 with a maximum weight of approximately 15 kg. This relationship between weight and density is shown in following figure 5.

[2] Railway Technical Research Institute, Tokyo Japan (2004). *Clarification of Phenomenon of Ballast Thrown up by Snow/Ice Falling from the Train*. (Electronic) Available: http://www.rtri.or.jp/rd/openpublic/seika/2001/01/safety_E02.html.

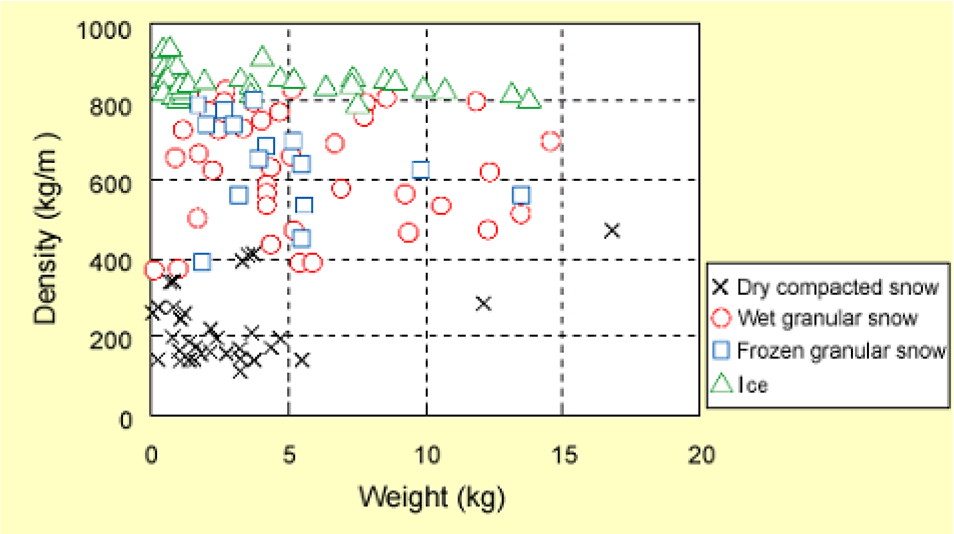

Figure 5. Relationship between weight and density of accreted snow and ice masses (by snow condition)[3].

Snow and ice in bogies and underframes must be reduced as far as possible. Proposed solutions:

- Surfaces that need to be free of snow and ice due to movements can e.g. be covered with plexiglass on a thin foam rubber layer. Any ice formation on these flexible plastic covers will crack and fall off for an applied force on the ice, see figure 6 below.

Figure 6. The thin plexiglass layer can be seen on the top of the bogie frame of a Swedish X2 trainset. The primary rubber suspension can be seen below to the right.

- In general, rounded surfaces as well as low friction surfaces are less subject to the build up of snow and ice and are therefore preferable.
- Avoid flat surfaces that move towards each other. A sharp edge is preferable when it comes to breaking the ice, see following figure 7.

[3] Ibid.

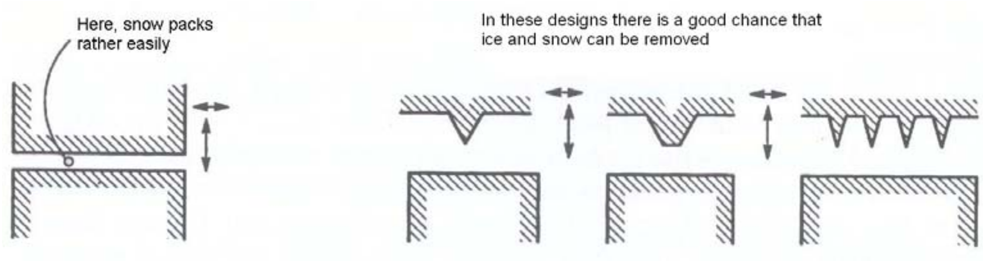

Figure 7. Examples of different surface designs[4].

- Anti-icing methods have been tested to prevent the build up of snow and ice i.e. the surfaces have been covered with a layer of propylene glycol or silicone. The methods seem promising so far.
- A cellular rubber fill can be used in holes in the bogies and around components in order to prevent snow gathering.
- Tests have been made with bellows around the whole upper part of the bogie on the X2 trailing bogies with tilt equipment.

  As long as the bellows are unbroken there is a positive effect but as soon as they break the whirling snow starts to pack inside even more than without the bellows. All the bellows are now dismounted.
- An open bogie design is favourable as it gathers less snow than a fairly closed design.
- Spoilers in different positions and of different design can be used to change the wind and snow flow around the bogie and carbody as well as around bogie and carbody components. This however must be tested and must function in both directions.
- Tests have been performed with some type of "Japanese paint" which should reduce the amount of snow that clings to a surface. The result has not been promising so far.
- Tests have been made with electrical heating of areas where the build up is extra problematic, but the water from the melted snow can give problems somewhere else as it whirls away.

  Some information indicates that heat is used on special locations on some Japanese trains with the purpose of preventing snow and ice from accumulating. An example of this is shown in the following figure 8. This kind of procedure with heated surfaces has also been tried in Sweden. However, these tests have been interrupted due to the large energy consumption and the problem with uncontrollable melting water. The lesson from this was once again that ice build ups on trains can not be prevented, but the effect of ice can be minimized.

[4] Andersson, Evert & Berg, Mats (2003). *Järnvägssystem och spårfordon del 2: Spårfordon*. Stockholm: KTH

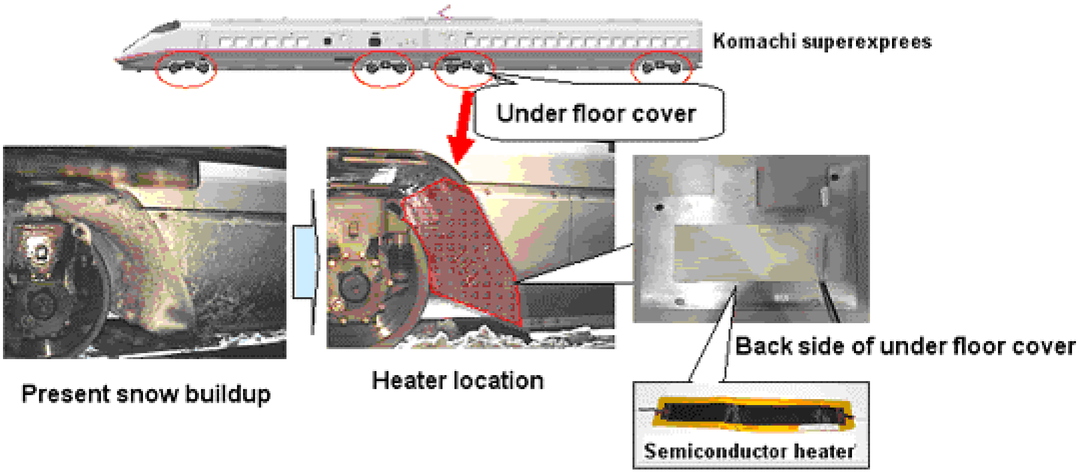

Figure 8. Japanese heating system to prevent snow build up under Shinkansen trains[5].

2.3 BOGIES

The bogies are exposed to the outer climate i.e. in this case low temperatures, dry and wet snow, ice and strong winds. Bogies will also be hit by ballast stones and by obstacles on or very close to the track. The bogie designer must take all these aspects into consideration including the extra weight of some hundreds of kilos of ice and the possibly reduced ability to motion in the suspension in the wintertime. The ice that builds up in the bogie can in worst cases break or tear off cables and components as well as block necessary movements, see figures 9 and 10.

Figure 9. Snow and ice gatherings in a bogie, in the beginning of the ice build-up.

[5] East Japan Railway Company (2006). *Preventing snow buildup under Shinkansen trains*. (Electronic) Available: http://www.jreast.co.jp/e/development/theme/safety/safety13.html

Figure 10. Snow and ice gatherings in a bogie after some time of operation.

2.3.1 WHEELS, AXLES AND AXLE BOXES

WHEELS

Flats on the wheels are in the winter period usually caused by brakes frozen to the wheels or discs after a train has been braked to stand-still. When the train is started again one or more axles might not rotate. Such a disturbance can be very difficult for the driver to identify. Also a not fully released brake (for instance due to ice blockings) will heat up the brake disc or the wheel rim, which in the end most likely results in damages.

Occasionally during winter, there can also be low adhesion causing wheels to slide on the rails.

Wheel flats in very cold climate can damage the rail and in worst cases break the rail every time the flat hits the rail head. Smaller flats left unattended may also in the long run damage the bearings.

To avoid these problems it has been suggested to:

- Have a durable wheel slide protection system installed.
- Let trains that stand still on horizontal tracks have released brakes if possible.
- Use hot box, hot wheel and wheel flat detectors to reduce the risks for damages and derailments.
- Heat the sand and the sand pipes used to increase adhesion to improve the function in winter climate.
- Mechanically protect sand pipes from ballast and ice projectiles.

AXLES

Initial cracks in axles can be caused by hits from the ballast. Alternatively ballast stones can get stuck for instance between an axle and a frame in the bogie. While the axle is rotating, the piece of macadam may cause a scratch around the axle. Cracks and scratches can lead to axle breakage and severe derailments.

Proposed measures to reduce axle damages in wintertime are as follows:

- Mounting of some type of rubber or plastic protection around the axle. However, such an arrangement makes a visual inspection of the outside of the axle impossible.
- Mounting of a protection above the axle, making it impossible for a piece of macadam to get stuck, see figure 11.
- Increasing the regular axle inspections during winter conditions.
- Taking measures to prevent the macadam to move, see chapter 3.7 Ballast pick-up.

Figure 11. Axle protection device.

AXLE BOXES

Axle boxes have to be sealed also when there are big temperature changes. Boxes and seals must be capable to withstand water and moisture both while running in high speed and while being de-iced in a workshop. If water is used for de-icing, poorly designed ventilation holes for bearing ventilation can be the reason for water ingress into the grease. Water in the grease damages a bearing in a much shorter time than originally expected. Therefore:

- The axle box design must be fit for purpose, i.e. if de-icing with cold or hot water is foreseen the axle boxes must tolerate that.
- The use of hot box detectors is of importance since damaged bearings can be identified in time.

2.3.2 SUSPENSION SYSTEMS

The suspension system consists of a number of components out of which the primary and the secondary suspension, the dampers and the anti-roll bars will be discussed from a winter perspective below. Following figure 12 gives an example of the tough conditions the suspension systems must withstand.

Figure 12. Bogie and carbody covered with ice.

PRIMARY AND SECONDARY SUSPENSION

The primary and secondary suspensions are needed to keep the track forces within the limits and to get a comfortable ride. Snow and ice can partly or fully short circuit the suspension and give higher track forces and bad running comfort. Low temperatures at winter time can also affect spring coefficients. To avoid such winter problems, the following measures have been recommended:

- Use a design that is less snow and ice collecting, this concerns bogie frames, rods, supports, connections etc.
- De-icing must be done at appropriate intervals.
- Prevent snow and ice to build up on surfaces moving towards each other, see chapter 2.2 Snow packing as well as the figures 7, 13 and 14.
- The use of covers around coil springs will prevent them from being packed with snow giving reduced suspension (problem: a visual inspection will be more difficult), see figure 12.
- Where rubber springs are used, the stiffness coefficient must allow for low temperatures.
- Components for height regulation in conjunction with air springs must be placed where ice and snow will not break them or block their movements.

Figure 13. Snow covers both for the secondary coil springs and for closing the gap between the car body and the bogie frame at the Finnish Sm3.

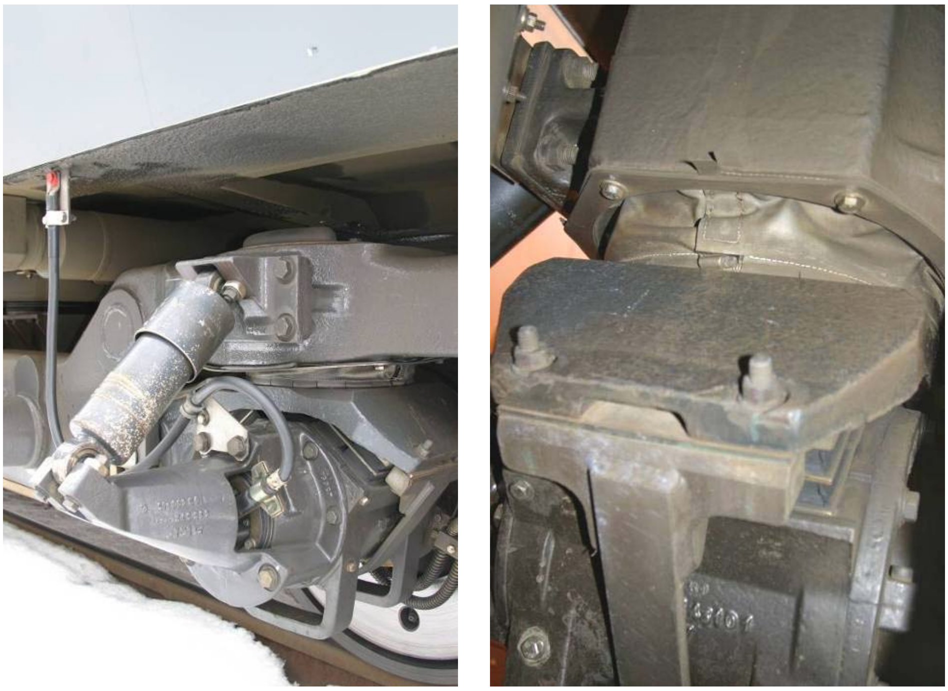

Figure 14. Snow covers/bellows around the primary suspension of the Norwegian BM71 seen from two perspectives.

DAMPERS

Many dampers, especially the axle box dampers, are located in very exposed positions (see for example figure 14 above) where they easily can get hit by ice and ballast. Proposed measures against these winter problems:

- Use mechanical protection around exposed dampers.
- Make sure that the damper oil and the sealings are suitable for low temperatures.

ANTI-ROLL BARS

Anti-roll bars are mainly used from a comfort point of view but also to prevent large lateral deflections of the pantographs. Nevertheless their rods and bearings need to be able to move and rotate and not be hindered by ice and snow. Proposals:

- Use bearings for the anti-roll bars fit for purpose.
- To reduce the risk of anti-roll bars to freeze, sufficient distance must be kept between the arms and rods and the bogie frame and other components.

2.3.3 TILTING OF THE CARBODY

Tilting trains are used to increase speeds on lines with many curves. This section deal with the specific problems that concern the tilt mechanism and the measuring device for the tilt angle.

TILT MECHANISM

In Scandinavia all tilting trains have an active hydraulic tilt system. If snow and/or ice starts to build up, the tilt mechanism can be blocked so the full tilting angle can not be achieved. This makes it necessary to reduce train speed or run with reduced passenger comfort.

The need for pantograph tilting is commented in chapter 2.9 Pantograph.

Some tilting trains have less winter problems with the tilt systems than others. This may depend on the region where they are run, but it is most probably an effect of how well the tilt system can be protected from the build-up of snow and ice and how well the tilt control system works in winter climate. Proposals for good winter durability:

- The hydraulic systems must be designed to work in a wide temperature range.
- Prevent snow from disturbing the tilt mechanism.

  This can be done either by having a very good sealed design around the tilt mechanism to prevent the snow from entering the area, or by making the area very open to make sure the whirling snow just blows away. In figure 15 an example of a rubber protection is shown.
- Make sure that water squirting from for instance brake discs not hit joints etc. in the tilt mechanism and turn to ice.

  This can be prevented by putting splash covers on well tried out locations. As it is difficult to foresee how water behaves in high speeds under the train it is more or less necessary to make tests to find the best locations.
- Prevent snow and ice to build up on surfaces moving towards each other, see chapter 2.2 Snow packing.

Figure 15. A rubber seal is mounted to prevent the snow to come further into the tilt mechanism.

MEASURING DEVICES

To get the best riding comfort, the tilting shall be optimized as regards when and how fast it shall work. Measuring devices are used to give the right tilting angle and the correct timing. For good functioning it is important that:

- Devices for acceleration measurements and angular measurements are placed where ice formations will not crash or disturb them or their connectors.
- The cabling is well protected.

  This means that there must be a protection from an electric and a magnetic point of view as well as from hits by ballast stones, ice blocks and other obstacles. Also the possibility of cables getting squeezed between moving parts such as rods for the tilting etc. covered with ice, must be taken into consideration.

2.3.4 RUNNING DYNAMICS

Snow gathering in the bogie will affect the running performance by reducing the spring movements, reducing the tilt angles on tilting trains and by the extra weight. The accumulated snow turns into ice due to the pressure from surfaces moving towards each other and/or from changes in the temperature. The blocked movements and the increased total weight will cause poorer running dynamics in the form of increased track forces, and reduced riding comfort as the speed is increased.

TRACK FORCES

Snow packing in the bogies and the underframe together with coldness can, apart from other aspects, have the following effects on the track forces:

- Reduced bogie movements due to snow and ice accumulation can affect the track forces and the forces between components on the vehicle above unacceptable levels.
- The increased stiffness in cold climate affects both the suspension system in the vehicle and the stiffness of the track, including the track bed. The higher stiffness increases the track forces. It may also affect the vibration frequencies of the wheel-rail system.

- The extra weight in bogies and carbodies will increase the track forces.

Proposed solutions to these problems are to use:

- Preventive measures to reduce snow packing, see chapter 2.2 Snow packing.
- Preventive de-icing. This has been tried to reduce the build up of snow and ice and is further described in chapter see 2.10.3 De-icing.

RIDING COMFORT

It is necessary to allow for the movements between the bogie and the carbody to get a comfortable running. Figure 16 shows a bogie where the snow packing has started but probably not yet affected the riding comfort

Figure 16. Snow packing in the X2 bogie.

To maintain a comfortable train ride the following has been pointed out as important:

- The build up of snow that later turns into ice must be prevented as far as possible to avoid a poor riding comfort.
- Shortcuts in the suspension system caused by snow and ice must be avoided or there will be increased noise level in the passenger compartments, see chapter 2.3.2 Suspension systems.

2.4 BRAKE SYSTEMS

The brakes are part of the safety system whose function must be guarantied regardless of climate. This is on the other hand not always the case in practise since there are influencing winter problems.

In this chapter some general important considerations concerning brake systems will first be pointed out, followed by the problems concerning disc and magnetic rail brakes.

The basic brake system is a pneumatic friction (adhesion) brake which involves winter problems such as freezing of air and moving parts and heat generation in the bogie/underframe.

If the compressed air system holds water it risks freezing or getting ice plugs in air tanks, drainage and gaskets. Other problems concern the use of inappropriate material or material combinations that shrinks and/or stiffens in cold. This can bring about untight air pipe couplings which make the reloading of air pressure take a long time and frequent recharging. In long trains this can mean difficulties to release the brakes. In the worst case the air cannot be reloaded at all, meaning that the train is not allowed to run at all. If the brake cylinders are not tight the braking effort can be reduced.

Unsuitable material can also result in a less efficient and slower brake movement that means less brake force. This could also be the result of a bad choice of lubrication. The restrained brake movements, concerning for example lever arms, can in addition be caused by snow and ice accumulations (for measures against snow and ice gathering, see chapter 2.2 Snow packing).

The reviewed more common or well known problems have been proposed to be avoided through the following measures:

- The compressor should be well covered and fitted with air dryers and filters. Since the compressor is a vital part of a train, redundancy is recommended as well.
- Some pneumatic components of the brake system may need to be placed in protected areas.

  This is a design measure that protects from snow and ice build-up. For example the components can be mounted on panels inside boxes in the underframe.

2.4.1 DISC BRAKES

During wintertime the disc brake performance can be lower compared to other seasons. In Sweden this problem was raised in the middle of the 1980's, when coaches with disc brakes became more common, and it has since then been a delicate topic. The nature of the problem is very severe as it has happened in both Norway and Sweden that stop signals have been passed due to disc brakes with reduced braking effort. The problem is expected to get worse with higher speeds as the brake distances then increase further. Another issue is that, if the problem with disc brakes in winter climate is not managed, it might be possible that operators are forced to have separate winter and summer time schedules with lower speeds in the wintertime if the train speeds increase further.

Significant for the problem is the occurrence of snow smoke. In such a case it is common that water, snow and/or ice build up on the brake discs. Eventually a film of water – more water than can be managed – forms on the disc surface causing the brake pads to aquaplane. This reduces the braking performance and can make the train stop beyond the intended point. Tests performed in Sweden[6] have shown very slow build up of the brake force may occur, which can be seen in figure 18 below.

The Swedish State Railways has made several winter tests in order to solve the problem with disc brakes in snow smoke. The testing activities were quite extensive and included a number of design measures that were investigated. Among these were for example disc covers, disc rings, various skirts and a polishing brake. Out of these, the disc covers appeared to be the best solution.

In Sweden each new train composition that is taken into service must undergo a deceleration test. The service-brake is tested as soon as the trainset reaches normal operating speed. The outcome of the test may require adjustments of ATC (Automatic Train Control) values and can result in a speed restriction. If the driver at any time suspects a reduced braking performance, he is instructed to do another deceleration test.

During operation it is in some cases hard to say whether the reduced brake performance is entirely due to the disc brakes. The adhesion may also be influenced as snow smoke may decrease the friction between wheel and rail. Test results have been conflicting on this specific matter. Some tests imply that snow smoke decreases the adhesion while other tests have not given results supporting this[7].

It is today suggested that the disc brake problem can be dealt with through the following measures:

- Instruct drivers on how to brake at the occurrence of snow smoke.

  In order to remove the ice and water film between the brake pad and disc the driver should exercise the brakes slightly. The pressure and heat generated by this procedure eventually

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[6] Gustavsson, Sven-Erik (1997). *Skydd för skivbromsar som utsätts för snörök*. SJ Laboratorierapport 9705-39p.

[7] Pettersson, Kalle & Wännman, Jan (2000). *Vinterprovtåget* 1999/2000. SJ Rapport R00-11.

gets rid of the ice and water. Drivers can also be instructed to perform more deceleration tests in order to ensure proper brake performance. Another method is to initiate the braking procedure in advance that is to say to apply the brakes earlier than normally before a planned stop.

- Equip trains with an automatic heating function.

  Instead of teaching the drivers how to break with the aim of removing the water and ice film an automatic function could perform the task. The function or “snow brake” automatically applies brake in intervals in order to maintain a better contact between disc and brake pad. The snow brake can for instance be set to be activated at special conditions such as when the temperature turns below zero degrees and the speed exceeds a certain level. This application has a great value in replacing the corresponding manual operation, but it means extra wear, extra energy consumption and the traction performance can be reduced in some special situations.

  This design could be compared to the polishing brake that the Swedish State Railways also tested. In these tests the solution was criticized as it generated further melting water that froze especially at the braking mechanism.

- Provide trains with better brake pads.

  A better contact between brake disc and brake pad can to some extent be accomplished through the use of brake pads that more effectively lead away water. Some trains are equipped with both better brake pads on the motor axles and snow brakes on the trailer axles.

- Install disc covers.

  The brake discs can be fitted with covers as seen in the following figure 17. In the late 1990’s disc covers were tested in Sweden and the measure proved to be quite successful. The appraisal was done that disc covers have a positive affect as regards reducing the risk for reduced brake effort during winter weather, however they do not solve the problem entirely. There were also some discovered problems; they complicate inspections, tend to gather ice and can inhibit the braking performance in severe coldness during long runs.

  A result from one of the tests with disc covers can be seen in figure 18, showing that still after 60 seconds only around 30 % of the brake force has been achieved on the unprotected disc compared to the one carrying disc covers.

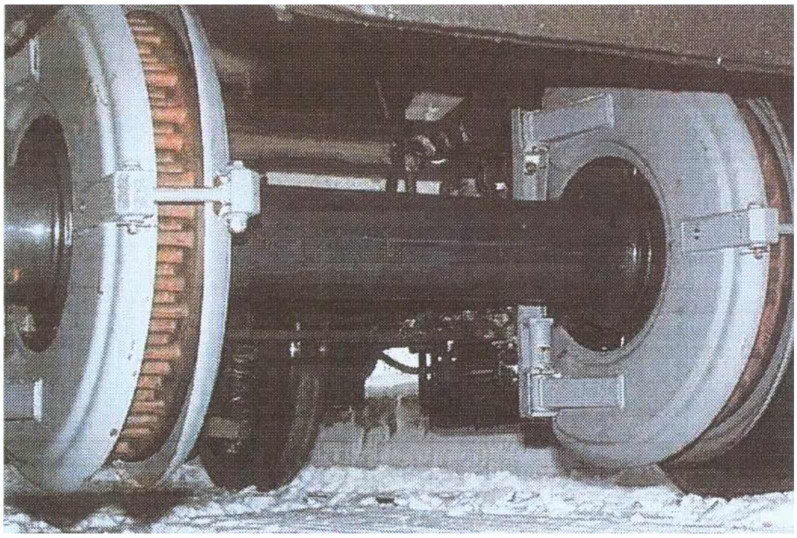

Figure 17. Disc covers for disc brakes[8].

[8] Ibid.

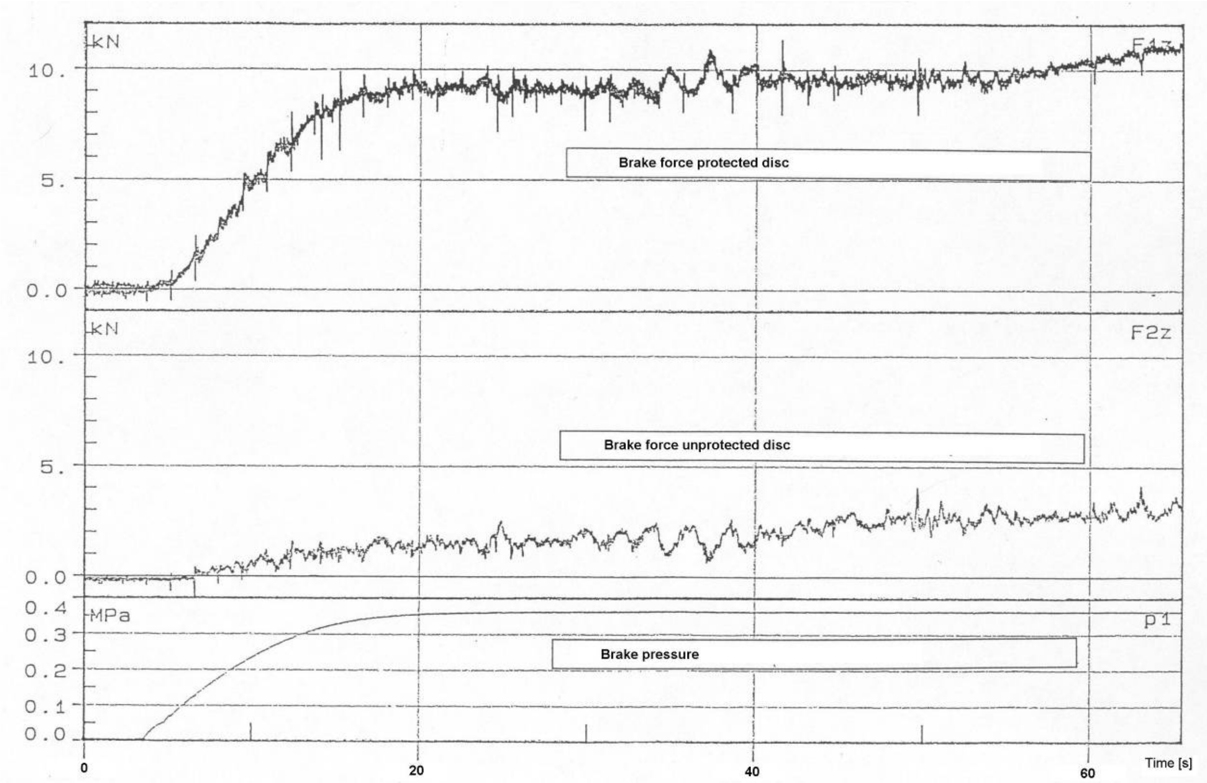

Figure 18. Full brake in 100 km/h with brake forces for disc brakes exposed to snow smoke. [9]
The disc protected by disc covers achieves full brake force, between 9 to 10 kN, during the whole brake procedure
The un-protected disc has a very slow build up of the brake force. Still after 60 s it is only approximately 30% of the demanded force.

[9] Gustavsson, Sven-Erik (1997). *Skydd för skivbromsar som utsätts för snörök*. SJ Laboratorierapport 9705-39p. The graph has been translated into English and therefore slightly modified.

Another winter problem with disc brakes appears as water is being thrown from the discs and freezes in the brake mechanism. The accumulated ice and snow then can cause lower brake forces and damage brake cylinder bellows and seals. It is therefore of importance to:

- Equip disc brakes with splash covers.

2.4.2 MAGNETIC RAIL BRAKES

Snow smoke is also a hassle for the magnetic rail brake. The whirling snow clings to the bogie area where it freezes and subsequently gathers more snow and ice. The brake problem occurs when the snow and ice accumulations keep the magnetic brake in place preventing it from falling down towards the rail. This problem with ice in the bogie, that influences the magnetic rail brake, has also been identified e.g. in Germany.

Magnetic rail brakes can also become unusable when ice and snow accumulate at the underside of the brake. The brake slide on the rail and cannot generate the intended brake force.

Normally, a non working magnetic rail brake results in speed restrictions, for example from 200 to 160 km/h. However, during operation it is hard to decide if a magnetic rail brake is not working properly since it is not used as often as the disc brakes.

The following measures have been put forward to facilitate the problems:

- Apply heat to the magnetic rail brake.

  Several magnetic rail brake designs contain heat that is applied in intervals. This seems to work in some situations. Nonetheless heating is expensive and can mean trouble with melting water. There are also examples were the heating has not been enough and the brake has been blocked by ice and snow from reaching the rail. It is therefore of importance to make sure that the heating and power intervals are set correctly.

- Protect magnetic rail brakes from water.

  The magnetic brake must be protected from water that comes from both the brake discs and the wheels. This can e.g. be accomplished through the use of splash covers.

- Inspect, exercise and if necessary de-ice the brake at end stations.

  The ice attached to the underside of the magnetic brake can be removed as the brake is exercised. It is therefore recommended to put the brake into effect and examine it at for example end stations.

The winter problems with both the disc and magnetic rail brakes unfortunately lead to uncertainty concerning how the emergency brake should be handled and for that reason it might be necessary to:

- Investigate how the emergency brake should be managed.

  During some winter conditions, the function of all types of brakes cannot be guaranteed. Winter can completely or partially put both disc brakes and magnetic rail brakes out of function. This can have severe consequences that increase with the speed. It also leads to uncertainties concerning how the emergency brake should be handled.

2.5 CARBODY

2.5.1 PASSENGER COMFORT

Passenger comfort includes many aspects as riding comfort, temperature, spacing, noise etc. From a high-speed winter perspective most of these factors are beyond the scope for this study. Here only aspects on cold climate are mentioned:

- The ventilation has to be designed to keep a normal air humidity also when lots of snow is drawn into the compartments.
- Passenger and driver cab ventilation intakes must be designed so that they do not get filled with snow and so that snow do not get inside, melts and causes problems.
- The heating and insulation shall be designed for maximum speed in cold windy climate both for the passengers and the driver. The heating must also be sufficient when the train stands at a platform with open doors.

2.5.2 DOORS AND STEPS

When platforms are not cleared in a proper way snow gets on the steps and into the trains together with the passengers. Both the snow and the water from the melted snow cause a lot of problems in door entrances. Also sand etc., which has been put on icy platforms, cause problems when it gets into the vehicles.

DOORS AND DOORWAYS

From a winter perspective the following shall be considered:

- Doors must be tight to prevent snow drift inside.

  This also means that both door and door sealing must be able to work as intended in severe winter conditions. Materials such as rubber are affected by the coldness and can obstruct door movements.
- Sand as well as ice and snow must be prevented from blocking door movements.
- Although the door blades shall be light, the insulation must be good as the temperature difference between inside and outside easily reaches 50 degrees Celsius with a high cooling effect on the outside.
- A passage lock, with for instance hot air at the entrances or an extra door to the passenger compartment, is suitable for especially trains with frequent stops with door opening and/or big entrance doors.

STEPS

There are two types of steps, fixed or movable. Independent of which solution is chosen, the steps must be safe to step on even if a lot of snow is dragged into the door entrances where it starts melting and gets slippery. Movable steps must function whether it is summer or winter. Therefore:

- The amount of snow, ice, sand etc. getting into the vehicle through door entrances must be reduced as far as possible.

  Snow and ice turns into water which needs to be taken care of. Sand hinders the functioning of doors and movable footsteps and can destroy the mechanisms.
- Make sure steps are not slippery.

  To avoid passenger accidents steps must not be slippery due to snow and ice when people are passing through the doorways. Slippery steps will make the stopping times longer as the passengers have to be more careful when they enter or leave the train.

  A possible solution, where applicable, would be to use perforated steps or surfaces in order to reduce the risk for snow and ice accretions.
- Steps folded or drawn into the carbody need to be heated to clear them from snow and ice till the next station. All equipment in this area must stand the fairly high temperatures that might arise.

2.5.3 GANGWAYS AND COUPLERS

GANGWAYS

Coldness puts extra demands on the gangway why the following issues should be regarded:

- From a passenger point of view the gangways need to be heated and isolated.
- The gangway material must allow for low temperatures without getting stiff as the vehicle must be able to negotiate all specified horizontal and/or vertical curves.
- The gangway material shall not wear abnormally when subjected to motions at low external temperatures.

COUPLERS

Automatic couplers of different kinds are usually used between vehicles or sets of vehicles in all high-speed operations. First of all they take the longitudinal forces (traction and braking). Secondly there often is an electric low voltage coupling and an air coupling integrated in the automatic coupler. To secure the functioning in winter conditions:

- The mechanical parts need to be lubricated especially for winter conditions.
- The electrical part of the coupler head needs to be heated to prevent snow and ice to interrupt the electrical signals.
- The air connection shall be protected with a tight cover when not coupled.
- When not in use the coupler shall be protected from snow and ice.
- The coupler pocket must be free from snow to let the coupler arm move up and down and sideways, compare with following figure 19. This could be achieved with a rubber membrane covering the coupler pocket.

Figure 19. Snow packed in the coupler pocket.

2.5.4 TANKS, HOSES AND PIPES

TANKS

Winter perspectives on tanks mainly include unprotected tanks hanging underneath carbodies. It has been recommended that the following shall be taken into consideration:

- Unprotected tanks underneath must be able to withstand hits from ballast and other different obstacles without breaking.
- Heating is needed to prevent water and WC-tanks from freezing.
- An automatic water tank emptying system shall be used in case the water temperature tends to drop below 0°C for instance while being parked in cold climate.

HOSES AND PIPES

To avoid water leakage problems from broken hoses and pipes, the following should be considered:

- Hoses and pipes shall have enough insulation to the outside to ensure that they do not freeze when the vehicle is running at full speed in cold climate. Alternatively they must be heated.
- Hoses for filling or emptying tanks must be prevented from ice build up and freezing by covers and/or heating.
- Too small diameters should be avoided, since water hoses and pipes with small inner diameter freeze easier than bigger ones.

2.5.5 UNDERFRAME

Passenger cars and multiple units have as much equipment as possible installed in the underframe or on the roof. Modern passenger car concepts – except low-floor vehicles – normally use underframes covered with skirts although the environment under the carbody is not always ideal.

The following steps have been proposed to reduce the risk for problems during winter conditions:

- The use of a large box, covering the entire underframe, can be a better solution compared to several smaller boxes. This is as it minimises the number of surfaces where snow can gather.
- Prevent snow from coming into the cabinets and boxes by having an overpressure in them.

  Although all doors and hatches must be tight, they must be easy to open and close for maintenance.
- Make sure that all equipment placed in the underframe is designed to withstand problems related to coldness, if this is not a heated area.
- Skirts and boxes must be protected and be able to withstand ballast pick-up and collisions with ice and other obstacles in the track.
- The equipment in the underframe must tolerate de-icing with water.

2.5.6 SNOW PLOUGH

There are at least two purposes with a snow plough:

- to remove snow and ice from the track when necessary,
- to throw bigger obstacles to the side and prevent them from coming under the vehicle thus reducing the risk for a derailment.

The design demands on the plough have to be specified for different types of operation. The following have been mentioned:

- The plough shall be designed to throw snow, ice and other obstacles to the side to avoid them from hitting equipment in the bogies or underframe or even to cause a derailment.
- In order to prevent derailment the wheel load on the first axle must not be reduced when the plough is in action.

  The plough must be designed to minimize the risk of lifting forces due to snow packing in front of the plough. A sharp-pointed plough is good to push snow to the side, but may on the other hand cause big lateral forces when running through asymmetrical snow heaps.
- For best functioning the plough shall of course be mounted as close to the rail as allowed regarding the gauge.

  From this point of view a plough mounted in the bogie will be the best, especially for tilting trains. On the other hand, the forces on the bogie may become too high and snow might be pushed up onto the bogie frame. A combination of a both a carbody mounted and bogie mounted plough could be an optimum.
- Special care must be given to the design of both the front and rear plough concerning the air pressure between them and the ballast, see chapter 3.7 Ballast pick-up.

2.5.7 TYPHOONS

Snow and water can create ice inside typhoons causing them to malfunction. Non working typhoons in Sweden result in that the speed is restricted to less than 40 km/h. In most cases typhoons are hard to reach as they are located on top of the roof close to the catenary. Therefore the problem cannot be solved during operation. That is why:

- Typhoons need to be either heated or encapsulated.

2.5.8 REAR MIRRORS

Rear mirrors are used by the driver to see signals given by the train staff or staff at the station at the rear of the train. They can also be replaced by video cameras giving the same function. In order to ensure a good view:

- Mirrors and/or video camera lenses/protections must be heated to avoid condense.

2.5.9 LIGHTS

Front and rear lights must always be visible. If the lights are out of order or cannot be seen due to snow or ice gatherings the consequence is a driving ban. Some light designs can get covered more easily than others, for instance xenon and diode lights that do not emit as much heat as regular light bulbs do. It has been proposed that:

- Lights should be heated or consist of regular light bulbs.

2.5.10 FRONT WINDOWS

The front windows need to be heated for the driver’s sight in the winter time. On a fast train the air cooling effect is normally very high. The heating power must compensate for the cooling but also take the glass length expansion coefficient into consideration. The front windows must also stand the full heating at stand still, if not temperature adjustable.

The wind screen wipers must be driven in such a way that the wiper motor is not destroyed if the wipers are frozen to the wind screen.

2.6 COLLISIONS WITH ANIMALS

From a high-speed winter perspective only collisions with bigger animals are regarded as a specific problem. In the winter with lots of snow, elks and reindeers prefer the cleared tracks compared to the deep snow beside the lines. Therefore in the Nordic countries collisions are fairly common in the winter time. They can be avoided by:

- Keeping fences along high-speed lines to keep the bigger animals out.
- Using “anti-elk-smells” along the line.

  During the Winter Olympics in Lillehammer elks were kept away from the track with the use of wolf urine on sticks along the line.

However all collisions can not be avoided. Whatever is run into, it must be hindered to come under the train to minimize the risk for derailment, see chapter 2.5.6 Snow plough. When the worst comes to the worst, the train fronts must be designed to minimize the damage from a collision. Apart from the front itself, this includes the coupler and the eventual coupler protection, the plough and the front windows. Means to reduce and make cleaning easy after a collision with an animal need be considered.

2.7 CABLES

The majority of the cables exposed to the outside climate and environment are located between cars and around the bogies where a lot of snow gathers. Cables must therefore be able to cope with the tough conditions that this location represents. This means first and foremost ice, snow and macadam stones that in one way or another hit the cables (for further information regarding striking stones see chapter 3.7 Ballast pick-up).

Eventually snow that sticks to the underframe and the cables turn into ice. Next the ice builds up even more snow and ice. In due course a cable can carry a large extra weight and risk breaking.

For tilting trains some cables might get extra long for example cables to angle measuring devices and can gather more snow and ice. Also ATC cables have proven to give problems as they, due to their location, are subjected to e.g. ballast pick-up.

Besides the extra weight, cables can get damaged by accumulated snow and ice in the bogie areas as the bogies move. An example of this is illustrated in following figure 20.

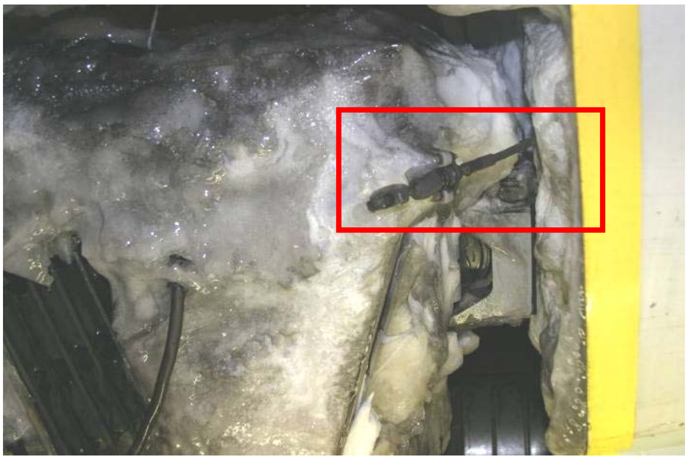

Figure 20. Example of a cable that risk getting squeezed between bogie and carbody.

To avoid cable problems the interviews performed suggest that following solutions should be taken into account:

- Eliminate as many free hanging cables as possible.

The problem could partly be solved if the amount of these cables were decreased. This could for example be accomplished by centralizing cables and by attaching them to the bogie centre through a bellows of some kind. This design would keep cables out of reach for snow and ice, but the design measure may possibly make maintenance more difficult.

- One option may be to place the traction motors in the carbody instead of in the bogie. Such a design eliminates some of the free hanging cables.
- Cables must be designed for the extra weight that ice and snow bring.

  Nonetheless it is an experience of today that already strengthened cables or their connections can break from the extra load of snow and ice.
- Fit cables with protection

  The spiral covers that cables in figure 21 are fitted with protect against hits from ice and macadam stones. The protections are made by plastic or stainless steel.

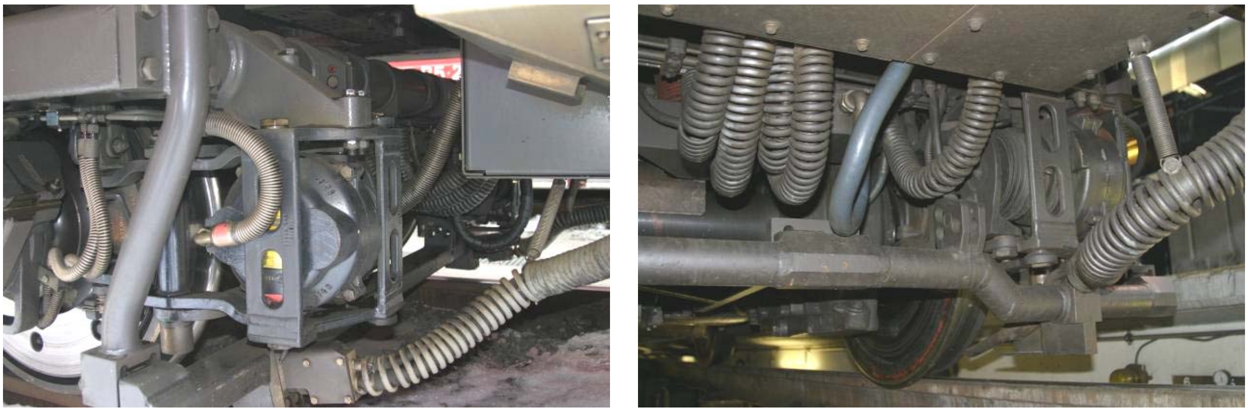

Figure 21. Cable protection devices on the Norwegian BM 71.

2.8 ELECTRIC TRACTION SYSTEMS

When it comes to the tractions systems most interviews have made it clear that proper ventilation of motors and other equipment is of great importance. Moisture is very hard, if not to say near impossible, to keep out and for that reason it must be ventilated away.

2.8.1 MOTORS AND COOLING SYSTEMS

Most electric motor related winter problems concern moisture. For example the forming of moisture at electrical components may cause poor isolation and short circuits. Water reaches the traction motors primarily through condense, cooling systems and occasionally as trains are de-iced with water. When water gets into a motor it can result in electric failures such as flash-overs that can cause harm to the motor. This was very much the case of commutator motors, but will partly still hold for asynchronous motors with fully isolated windings. The isolation may be damaged by the voltage stresses in combination with moisture, dirt and ice.

Condense is primarily caused by temperature differences. A train that is taken either in or out of workshops is often subjected to condense. There can be water drops that condensate over the whole train and sometimes even condensation inside the motors and other electronic equipment. Temperature differences of 60ºC are not unusual in these cases.

The cooling system is an entrance for snow and consequently water. Snow can push inside to motors and blowers via cooling air intakes. The snow can then either turn into water or freeze to ice and may block the cooling system. The ice created can later on become a problem if it turns into damp air. It may also harm moving parts.

In order to avoid the problems described above the following design principles have been recommended:

- Place air intakes high.

  The snow smoke that surrounds a running train is most severe at the vehicle's lower parts. Thus, cooling air intakes should be placed high up at the roof. They should be fitted with filters.

  In figures 22 and 23 there are examples of rolling stock with air intakes placed high at the roofs.

- Make sure that air intake designs are appropriate for Scandinavian winter.

  Air intakes located for example in the bogie for non forced cooling need filters that meet winter requirements. These filters must make sure that only air passes and not any snow. It has been experienced that some air intake designs adopted in other countries do not work in Scandinavian winter conditions.

- Focus on ventilation instead of sealed designs

  It is very difficult to make designs absolutely sealed as humid air is almost impossible to keep out. Therefore efforts should be made to air and ventilate spaces. Electronic equipment should be installed in separate and well ventilated cabinets inside the vehicle as far as possible.

Figure 22. Above: High positioned air intakes on the Finnish Sm3.

Figure 23. Left: High positioned air intakes on the Norwegian BM71.

2.8.2 MOTOR CONTROL SYSTEMS

There have been problems were electronic equipment such as current converters have been exposed to snow. Normally being enclosed in the underframe, this equipment is rather well protected. Nevertheless if there is a built-in underpressure in this area snow will be dragged in and water can damage the electronics. To see to this problem:

- Motor control systems should be placed in protected areas such as cabinets with overpressure.

2.9 PANTOGRAPH

The higher the speed is, the more delicate the current collection will be. If winter conditions are added a number of problems will arise.

It is recommended to have a redundant system, i.e. two separate pantographs. If one gets damaged the other one can be raised and used instead. The need is normally higher in winter conditions.

The pantograph consists of four sensitive parts:

- The carbon strip, giving the current transmission from the contact wire to the pantograph
- The pantograph head with its suspension for a continuous current collection
- The normally air operated pantograph’s lower and upper arms and their linkage including the emergency drop.
- For tilting vehicles – the anti-tilt mechanism.

2.9.1 CARBON STRIP

The wear of the carbon increases dramatically when there is rime on the overhead wire. This gives the result that, due to the arcing, either the wear is so big that the carbon breaks or the heat destroys the fastening of the carbon to the carrier. Hits from foreign obstacles can also destroy the carbon and the risk for tearing down the catenary is very big. Proposals to reduce the problems:

- Shorten the inspection intervals during periods of severe conditions to secure that damaged carbon strips are detected and changed before being put in operation.
- Make sure that the fastening of the carbon to the carrier is temperature stable over a wide temperature range.

  Some types of mountings of the carbon strip to the aluminium carrier can be sensitive to the temperature and temperatures well over 200 °C have been measured on the carrier due to rime.
- Remove trees and branches that may get too close to the wires in case of much snow.
- Remove ice formations in tunnels that risk hitting a passing pantograph.
- Use a quick-drop or emergency-drop function with a sensor normally mounted under the carbon strip (an air pressurised carbon strip). This reduces the number of catenary break-downs and is a requirement in the high-speed rolling stock TSI[10].
- Use integrated carbon horns instead of metal horns to reduce the risk to damage the contact wire.
- Power control systems should not be sensitive to short power losses which may occur when there is a lot of rime on the contact wire.

  Power losses due to rime that can cause some power control systems to go down and/or even activate the quick-drop function of the pantograph.

2.9.2 PANTOGRAPH HEAD

The pantograph head is designed to give a constant or very slowly increasing force towards the overhead contact wire when the speed is raised up to the maximum speed. This shall also be the case when a vehicle is running in the opposite direction. Proposals:

- Make sure that the damping rate does not exceed limited values even in strong coldness.
- Movements in the head must not be blocked by ice as the current collection can be disturbed.

[10] Lerouge, B & Alibert, B (2005). *Draft Revised HS RST TSI (main text)*. Brussels: AEIF 22.12.2005.

- Use preventive de-icing. Ice on airfoils can reduce their influence to control the up force and result in poor current collection as the high-speed wind effects are very big.
- Stationary pantograph detectors can be used to monitor the forces between the overhead wire and the pantograph and give an alarm if the forces exceed certain limits.

2.9.3 RAISING AND LOWERING OF THE PANTOGRAPH

Raising of a pantograph is done with the help of compressed air. The lowering follows by the weight of the pantograph when the air pressure is reduced. The following has been recommended for good operation during winter conditions:

- Air dryers must be used to avoid that damp air freezes in valves etc at low temperatures. Especially the lowering of the pantograph is of importance from an electrical safety aspect.
- Prevent snow and ice from gathering on the pantograph arms.

  The high-speed wind effects are very big. Ice or snow on arms or aerofoils can change the up force and hence the current collection. Promising tests have been done with silicone on the arms to reduce the amount of snow and ice that normally gather there.
- The initial lifting force must be big enough to overcome the influence from snow and ice.

  Wet snow or rain freezes on the arms when the pantograph is down. When the pantograph is to be risen the air pressure giving the force for the initial lift has to be big enough to do so.

2.9.4 PANTOGRAPHS ON TILTING VEHICLES

The following shall be kept in mind regarding pantographs on tilting trains:

- In areas where water cannot always be kept out, make sure that if the water freezes to ice, either the ice does not disturb the function, or arrange for heating where needed.
- The device that keeps the pantograph in the right position during the carbody tilting must be durable for winter conditions.
- Areas around moving parts must be designed to avoid snow packing. This is related both to the need for the movements but also to the need for sufficient insulation distances to the high voltage equipment.

2.10 ROLLING STOCK MAINTENANCE

During the winter months maintenance has been described as the double work compared to the normal conditions at summer. For instance, the bogie and underframe are difficult to inspect and handle since these areas often are filled with snow and ice. The need of corrective maintenance is increased. Time consuming de-icing is often required.

In this section winter issues related to rolling stock maintenance are presented.

2.10.1 PREVENTIVE MEASURES

Trains need to be de-iced and they are in general more delayed at winters. This results in a reduced time that the trains are available for effective maintenance. Together with the often poor workshop track capacity the tight work schedule may have an adverse effect on quality. The situation sets off the importance of being well prepared:

- Take preventive measures in time.

Preventive measures must be taken before the winter season starts in order to obtain the best possible condition of the vehicle fleet. For example the heating, ventilation, steps, filters, pneumatic system etc need to be inspected and maintenance status improved as necessary.

- Reschedule preventive maintenance

  If possible, scheduled maintenance should be removed from the most critical winter season so that maintenance can focus on corrective actions and the additional time required for any type of maintenance actions.

2.10.2 VEHICLE FLEET

A big frequent problem in the winter time is the shortage of rolling stock. This is the result of an increased number of failures and the additional time required for the maintenance. Therefore:

- A larger fleet of vehicles is often needed wintertime or the planned service may have to be reduced.

2.10.3 DE-ICING

De-icing facilities are musts at wintertime – trains need to be cleared from snow and ice before maintenance can take place in the depots as well as to maintain proper performance in operation.

There are several problems related to de-icing:

- De-icing takes a long time; several hours per trainset is normal. This however depends on the train design, the ice and snow build up as well as the method of de-icing. If possible the time for de-icing needs to be shortened without increased risk for rolling stock damages.
- In general the de-icing capacity – seen to number and/or capacity of installations – is insufficient.
- The need of de-icing and de-icing capacity may vary over a country as well as by time. This means that vehicle circulations may need to be changed during the wintertime.
- Today there are no de-icing methods in operation that are good enough:
  - It is difficult to de-ice with normal hot water since this method may give problems later on. The slightest remaining water will most likely turn into ice and cause snow accumulation. Some actors even consider this way of de-icing as a failure.
  - De-icing with hot air takes long time. Eight hours for a train is not unusual in this case.
  - De-icing by glycol means problems to take care of glycol dropping from the train.
- De-icing is expensive. It requires a lot of space and energy. The operation itself is very costly.
- Trains must be designed with respect to de-icing and the de-icing method applied. In particular, if hot water is used cubicles and sealings must be waterproof.
- If, after de-icing, a train is taken outside before it has dried up, the water that remains may freeze and the train then rapidly gathers more snow and ice during operation. This kind of unfulfilled de-icing can in some cases be worse than no de-icing at all. Temperature differences at 60ºC are not unusual.

  This problem also concerns workshops in general. A train that spends time inside a workshop can hold water that will freeze quickly in the outside climate.

- Interviews indicate that during extra harsh circumstances high pressure de-icing with hot water in fire hoses is used. Mechanical means may be used. This is the practical emergency solution, no matter what the instructions say.

The de-icing problems are proposed to be solved by the following measures:

- Increase the number of de-icing installations or decrease the de-icing demand.

  With present de-icing methods the capacity problem can be solved with increased number or size of de-icing plants. With more vehicles the de-icing demand could possibly be lowered.

- Make sure there is no water or moisture left on the train before it is taken outside – of special importance is the brake system.

  This solution is not difficult, but it requires time. However the time can be shortened through warm air drying.

- Design underframe parts with round surfaces where possible since they are easier to de-ice.

  This design aspect has been discussed earlier under section 2.2 Snow packing in order to prevent accumulation of snow and ice.

- Use de-icing with propylene glycol.

  De-icing is very much a question of transferring energy and for that glycol is much more efficient compared to air and even water. Airlines have used propylene glycol for de-icing for over 20 years but it is not until now that the technology has been transferred to the railways in Scandinavia. In Hagalund, Sweden, there is a test installation (earlier there was also a test facility in Drammen, Norway). The facility is rather simple and does not demand a lot of space. In figures 24 and 25 pictures of the installations in Hagalund and Drammen are shown.

  The facility in Hagalund has a tank containing 16 000 litres of propylene glycol which is heated to +90ºC. The liquid is applied to the train with a low pressure of approximately 0,6 bar through adjustable pipes. The idea is to de-ice the train outside while in motion. Between the rails are vessels that collect superfluous fluid which is reused. It takes about 40 seconds to de-ice a bogie and approximately 90 % of the fluid is reused. However, both these numbers depend on the bogie design and the ice and snow accumulation.

  The propylene glycol that remains on the train is considered to have an anti-icing effect. Propylene glycol consists of round shaped molecules while snow molecules are sharp. This makes it hard for snow to stick to propylene glycol. Interviewed persons are convinced that the anti-ice effect works but the question is for how long. Propylene glycol is water soluble.

  If propylene glycol de-icing would even work half as well as expected, it has several benefits compared to conventional de-icing. It is more cost and time efficient, enables anti-icing and can even be made portable. There have also been tests indicating that propylene glycol due to its viscosity will not push into nooks as easy as water does.

  Propylene glycol is considered less harmful to the environment compared to ethylene glycol. It is classified as environmentally friendly and is water soluble. However, propylene glycol has a high biological oxygen demand. It can have harmful effects on foremost aquatic life and cause bad smells. Thus, it is of importance to control the propylene glycol waste.

Figure 24. The de-icing facility in Hagalund, Sweden.

Figure 25. De-icing with propylene glycol in Drammen, Norway.

2.11 OPERATION

No matter if a high-speed train service – with aspects on both rolling stock and infrastructure – runs smooth during winter, running on other line sections and other trains can cause disruptions. This comes to that:

- Since train services are extra vulnerable wintertime more track capacity is needed at certain locations.
- In mixed traffic, attention has to be paid to the winter maintenance of the conventional trains as well.

2.12 TRAIN CONCEPTS

The majority of high speed trains in Scandinavia are electric multiple units (EMU:s) and not locomotives with coaches. Locomotives are in general more simple to design for winter conditions compared to EMU:s. They are normally heavier and more robust. Tilting trains are problematic from a winter perspective (for more detailed tilting problems see chapter 2.3.3 Tilting of the carbody).

High-speed trains, and especially EMU designs, have in general a bigger need for snow cleared tracks.

- EMU designs might require specific operational considerations.

  In case of heavy snowfall it can be required to have a locomotive run ahead of EMU:s in order to clear the track. This is e.g. the situation in Finland during winters where a locomotive hauled train must run the line every day before the first high speed train enters service[11]. Also in Norway, locomotives are run for snow clearing ahead of high-speed multiple units during severe winter conditions.

When it comes to low floor designs it is very uncertain how this kind of rolling stock will do in winter conditions. Low floor often means that equipment need to be placed on top of the roof. On the roof the equipment is exposed to snowfalls and snow smoke, which in worst case could contain gravel.

2.13 AUTHORITY APPROVALS AND DEMANDS

An authority approval is not a guarantee that rolling stock related winter problems will not occur. This has of course to do with many things for example how the maintenance is carried out. The question is if there are problems that could be avoided through other authority demands and routines?

In the Swedish handbook for authority approvals there is nothing specific stated concerning winter conditions. The procedure is to perform winter tests that all new types of rolling stock must undergo and the supplier is responsible for the test. The authority may contribute to the test by discussing its contents and take decisions based on the test report. The following is stated in the Swedish Rail Agency's praxis for approval of rolling stock in winter conditions (the quote has been translated into English):

"*For locomotives and multiple units the snow and winter durability shall be shown with a winter test for at least four weeks in a snow covered area. Up to half of this time may be exchanged for a climate chamber test. Exceptions are given for locomotives and multiple units that have been in service in Norway for at least two winters.*

For other rolling stock the snow and winter durability shall be shown through experiences of service during at least one winter month in a snow covered area.

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[11] (2006). *High-speed operation in winter conditions*. Helsinki: ANSERI Consultants Ltd.

Freight wagons and other rolling stock with tread brakes shall have brake pads approved by the Swedish Rail Agency. These approvals are based upon winter tests with brake pads in different materials. Freight wagons approved in other EU-countries with other types of brake pads are allowed to operate in the whole of Sweden independent of season according to TSI WAG 7.7.2.3.1.5 (provided that the temperature demand is fulfilled."

(the Swedish Rail Agency 2006)

If the winter at the time of the test is considered to be too mild, the rolling stock will only be approved temporarily and further testing when possible will be required.

There are no standard procedures for how tests shall be carried out. As a consequence, an already approved vehicle may in fact face problems during more severe winters. This has happened and it caused severe problems leading to temporarily withdrawal of the rolling stock since the problem involved the brake system. This means that:

- Authority approvals are not bullet proof and may need to be reviewed especially for higher speeds (above 200 km/h) since problems for this speed range is partially unknown.

During really harsh winters, temperatures down to -40 ºC occur in northern Europe. Several interviews indicate that it is uncertain if electronic equipment such as computers and touch screens are able to start-up in these low temperatures. Design solutions must be used to ensure start-up and operation of a train at external temperatures down to -40 ºC.

According to the Swedish Rail Agency's praxis for rolling stock approvals the following is applied in Sweden as regards the outside temperature (the quote has been translated into English):

"*Rolling stock approved for the whole of Sweden shall be specified for a temperature area Tn (-40ºC – +35ºC). Exceptions can be accepted for rolling stock specified for:*

Lowest temperature	***Allowed geographical area***
-25ºC:	*Sweden except north of a line Kil – Frövi – Sala – Uppsala.*
-30ºC:	*Sweden except north of a line Härnösand – Söderhamn – Bollnäs – Mora.*
-35ºC:	*Sweden except north of a line Storlien – Östersund – Boden – Luleå.*
-40ºC:	*All of Sweden*."

(the Swedish Rail Agency 2006)

In the following figure 26 these geographical temperature areas, for rolling stock, are shown.

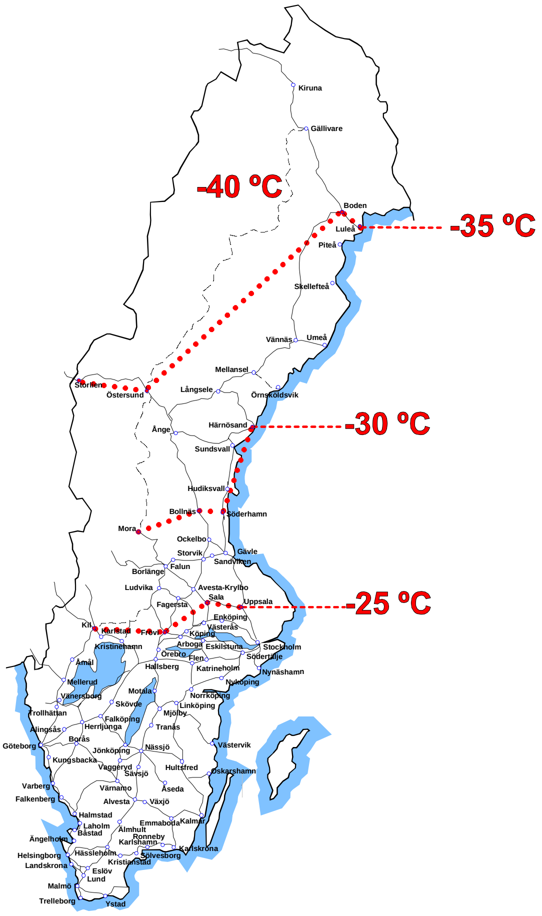

Figure 26. Geographical temperature areas for rolling stock as specified by the Swedish Rail Agency.

For the time being there are three European temperature classes; T1: -25 to +40 ºC, T2: -40 to +35 ºC and T3: -25 to +45 ºC. T1 is the basic level and it is up to the rolling stock buyer to decide what class should be applied. There are examples of rolling stock in Scandinavia today that only comply with the T1 standard. Together with the fact that many rolling stock winter problems can be avoided during the design phase the buyer plays a very important role in procurement and therefore:

- Authorities should ensure that there are proper design requirements and guidelines for winter performance of rolling stock to be used in Nordic winter operations.

3 INFRASTRUCTURE

This chapter on infrastructure problems is structured in a similar way as the previous on rolling stock. It contains organizational issues as well as specific problems related to track and catenary. It starts by discussing the worst weather condition from the infrastructure perspective. All reported problems are considered to be high-speed dependent according to the definition in chapter 1.5 Definitions.

In order to present the problem on a more general level this chapter opens with a Japanese quote with reference to figure 27.

"*Snow can seriously interfere with train operations. Trains may be stopped by snow accumulating on the tracks and turnouts, or by drifting snow or avalanches. Avalanches and snow drifts can derail a train, snow can damage rolling stock, snow adhering to rolling stock may fall off while the train is in motion and cause an accident, and railway structures may collapse under the weight of snow.*

A number of structures can be erected to prevent these and other problems. The snow can also be removed before it becomes a serious nuisance using rotary snowplows or Russel (pushing) snowplows. In addition, winter schedules can be devised to permit the alternate use of snowplows and trains on the same track. Train operation controls can be implemented on a phased basis, depending on the amount of snow on the tracks and snow removal conditions.

Avalanche risk is evaluated from the air using helicopters, and on the ground during patrols. When an avalanche is anticipated, especially during the snowmelt season, special surveillance measures are taken to protect rail operations. A different problem is seen in tunnels—freezing of leaking water. To prevent this, structures equipped with thermal insulators are being developed and installed.

The following measures are taken to protect Shinkansen from snow damage. In the case of the Tokaido Shinkansen line, sprinklers spray water on ballasted track during snowfalls. This makes snow wet, otherwise it would fly up when trains speed by, and prevents snow from adhering to rolling stock.

The Tohoku and Joetsu shinkansen lines run through areas subject to greater snowfalls. Ballasted track sections are shorter there, and rolling stock is designed to inhibit snow adherence. Viaducts on the Tohoku Shinkansen line have been constructed to withstand snow depth equivalent to the annual return in a 10-year period. On the Joetsu Shinkansen line, water sprinklers melt snow on track sections in the plains and on long, tunnel-free sections in mountainous areas. Snow sheds and snow shelters have been constructed over shorter sections between tunnels.

RTRI is now developing an avalanche detection and alarm system for railway tracks. We have completed basic research on a system that will be extremely accurate in detecting the occurrence of avalanches and evaluating their size, and that will issue alarms when required. Our prototype experiments have indicated that the system can perform these functions and we have every reason to believe that it will be put to practical use soon."

(Noguchi & Fuji 2000)

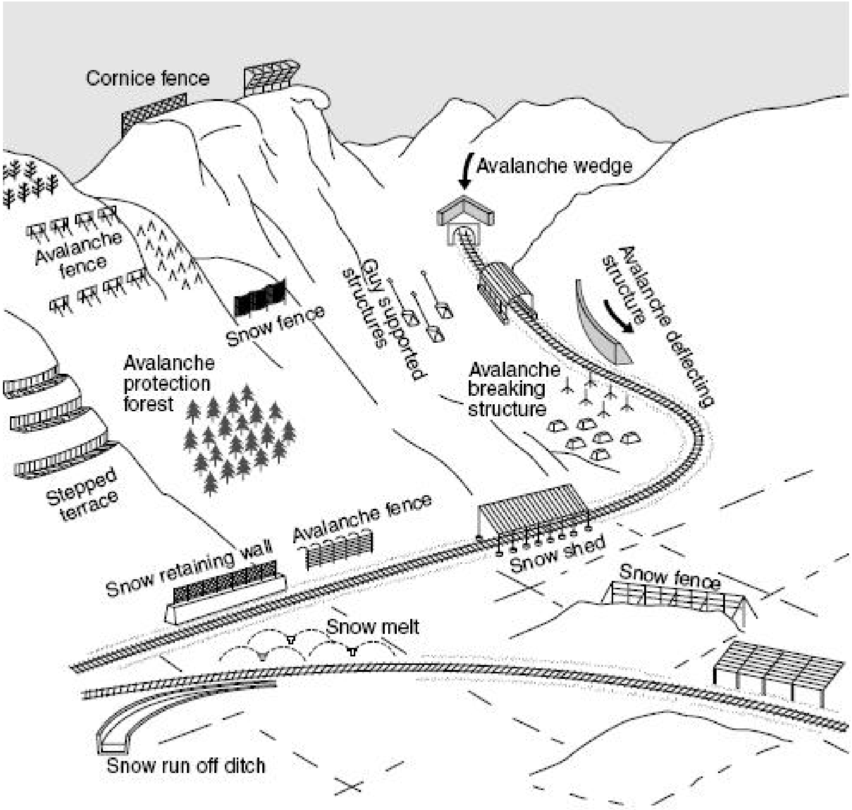

Figure 27. Japanese snow protection system in the infrastructure[12].

3.1 WORST WEATHER CONDITIONS

Like for the rolling stock it is hard to make out a general conclusion about the worst weather for the infrastructure. The most common and most severe problems differ from year to year. The track and the overhead catenary system are affected differently by the various weather conditions. In this case it is also hard to distinguish between track and catenary winter problems when it comes to which are the most crucial to the traffic operation.

Considering the track there are two situations that cause most harm to the railway operation. These are heavy snowfall and snow in combination with wind. The extreme snowfalls are really hard to handle and especially at stations where there are normally no good places to keep the removed snow. At these yards there are also switches that may require manual snow clearing which is a time consuming procedure. Wind can complicate the situation further by spreading not properly cleared snow over the station and its switches.

Wind and snow is a devastating combination for switches. This as snow is being transported horizontally and ends up between the main rail and the switch's tongue. The switch is then put out of function.

Even for the catenary snow can be harmful if it causes trees and branches to fall into the free space and then damage either the contact wire or the pantograph. It is in general the weather that affects the pantograph that brings the largest problems. The overhead wire is a vulnerable system. Damage or malfunction of the pantograph often causes tear down of the overhead wire. There are two kinds of unfavourable conditions. The first is rime on the catenary, which increases with lowered temperatures.

[12] Noguchi, Tatsuo & Fujii, Toshishige (2000). Minimizing the Effect of Natural Disasters, *Japan Railway& Transport Review,* no. 23, pp. 52-59.

The second concerns the forming of ice on the pantograph. Ice on the overhead wire also occurs, but is rare. It is especially wet snow in the temperatures around zero that easily turns into ice. Ice is also created very fast on the pantograph at the occurrence of fog and minus degrees, especially at high speeds due to the cooling effect.

3.2 ORGANIZATION

In order to cope with the problems that may arise during winter, the infrastructure managers set up winter preparedness plans. The plans are discussed with other involved parties such as the operators. An emergency preparedness plan describes how to handle and limit disturbances that may arise due to weather during wintertime. The plan also describes organisation and prioritized tracks and stations on each route etc. In addition to these preparations, infrastructure managers prepare for winter through several other measures. Resources such as machines, personnel, subcontractors etc. are prepared. Snow covers are assembled, heat in switches controlled and the tracks and areas close by are cleared. However, despite all the preparatory work there are several problems related to the infrastructure.

Some say that the origin of the setbacks is due to lack of communication between the infrastructure managers and operators for instance when it comes to which tracks that should be prioritized. The emergency preparedness plans are also criticized for not being proactive enough.

A large problem that has come to light throughout this investigation is the fact that maintenance activities such as clearing the track from snow somewhat lack comprehensive coordination. This kind of responsibility is divided among geographical areas, organizations and persons meaning that optimisation takes place from rather small regional perspectives. That is why:

- Winter demands comprehensive coordination – an organization that takes a general approach on winter issues.

People working with the daily infrastructure operation have sometimes problems to receiving the proper information in the right time. Too often is the dialog with the traffic control not good enough concerning preventive measures. In order to be more pro-active:

- Snow removal staffs need information about the operation conditions more frequent and in time.

Train services depend on the infrastructure. It can be argued as somewhat peculiar that mainly operators and their customers benefit from an infrastructure in good condition. With the present quality system, infrastructure managers are without proper incentives and maintenance personnel can in practice only receive criticism. It is on the other hand not fair that operators should carry all the risks by themselves. For that reason it has been argued that:

- New terms for infrastructure quality, containing both penalties and bonuses, should be considered.

In the eyes of the public, winter appears to strike as a surprise to all train services. More or less the same problems occur every year. To partly overcome this problem it has been proposed to produce:

- Better information on weather forecasts.

  Infrastructure managers need access to better weather forecasts and preferable weather prognosis adjusted to the railway. Today there are special systems regarding for instance snow, measuring and forecasting ice on the overhead wire, rail temperature, wind etc. Through these geographical information systems the preventive maintenance actions of the infrastructure could be arranged easier.

3.3 TRACK

As well as for the rolling stock an excessive amount of extra work must normally be put on the maintenance of the track at winter. There are a lot of winter problems that are being generated during operation at bad infrastructure conditions. For instance, a poor track status can result in rolling stock damages which subsequently may harm the track. More inspections of the track are therefore required during wintertime.

3.3.1 SNOW CLEARING

The clearing of snow is a large problem wintertime primary as it can both be difficult to perform and since there can be severe consequences in train operations if the snow clearing is not properly done.

To clear the track from snow is many times easier said than done. The action takes time to carry out and depends to a large extent on the access to the track. Often snow clearing can only take place during the night time when there is a reduction in the traffic. Otherwise, snow clearing can cause train delays and even cancellations. Snow clearing can also be hard to plan since it may depend on other more acute track maintenance demands.

During heavy winters with a lot of snow there are also problems to store the snow that have been cleared from the track. If the snow must be transported away there is trouble with the disposal since the snow is considered to be contaminated. The stations are more problematic to clear from snow than the line itself. This is due to the shortage of storage space. There are however also locations on the line that lack space for snow.

Throughout this investigation four critical areas regarding preventive snow clearing have been reported. These are;

- switches,
- local areas where the snow does not blow off,
- platform tracks (platforms can be hard to clear since the snow and ice should not be shovelled down on the track) and
- not prioritized tracks that carry slower traffic (snow on these tracks can get to already cleared tracks as slower traffic can push the snow ahead of the trains).

If the snow clearing is not performed in a proper way there is a risk of the following consequences:

- Derailments.

  Both ice and snow in the track can cause a train to derail. Snowdrifts as well as ice that reach high up on the rails are considered dangerous. Ice can be common in tracks that are located near bridges and watercourses.

- Trains get caught and/or lose time.

  A train’s running resistance increases with the snow masses in the track which affects the running time. Sometimes these masses can even cause a train to get stuck. Even if the track has been cleared from snow the space next to the track can be full so that snow infringe on the free space.

- Passenger injuries at platforms.

  At platforms passengers risk slipping and falling if the ice and snow is not removed.

- Snow gets into the trains and cause difficulties, see chapter 2.5.2 Doors and steps.
- Damaged rolling stock equipment.

Patches and lumps of ice that get in a train's way can damage rolling stock equipment. Collected ice blocks nearby the tracks or on the tracks – which have dropped down from trains, tunnels or from bridges – can destroy parts of the train, e.g. windows, underframe or roof fairings. The higher the speed, the higher is the possibility of damages by flying ice pieces.

- Non functioning switches.

  Switches are very sensitive infrastructure components that in some situations need almost constant clearing. For further information about this subject see following chapter 3.4 Switches.

In order to assist snow clearing and avoid snow gatherings on the track a number of measures have been suggested:

- Create space for snow.

  It is needed to have areas next to the track available for snow storage. Otherwise snow is consequently being packed along the track and may sooner or later get into the free space. There are examples of trains getting stuck due to snow pressed against walls in tunnels.

- Platforms could be heated.

  Such a system would reduce the need for snow clearing, but the solution is believed to be expensive.

- Cuttings need to be designed in such way that they do not get blocked by snow.

  A long cutting is an example of an area that needs space for snow. This is also a Japanese learning according to figure 28, which shows that a wider space is needed for cuttings located in snow affected areas. A design like this that respects winter also eases ploughing.

- Dedicate tracks to frequent high-speed services.

  A frequent high-speed train service tends to clear the line by itself and keeps it clean. This may imply that snow covers are not needed in switches on lines dedicated to high-speed services.

- Make sure that the track is properly drained.
- Snow fences can be required at some locations with specific risk of snow drifts.

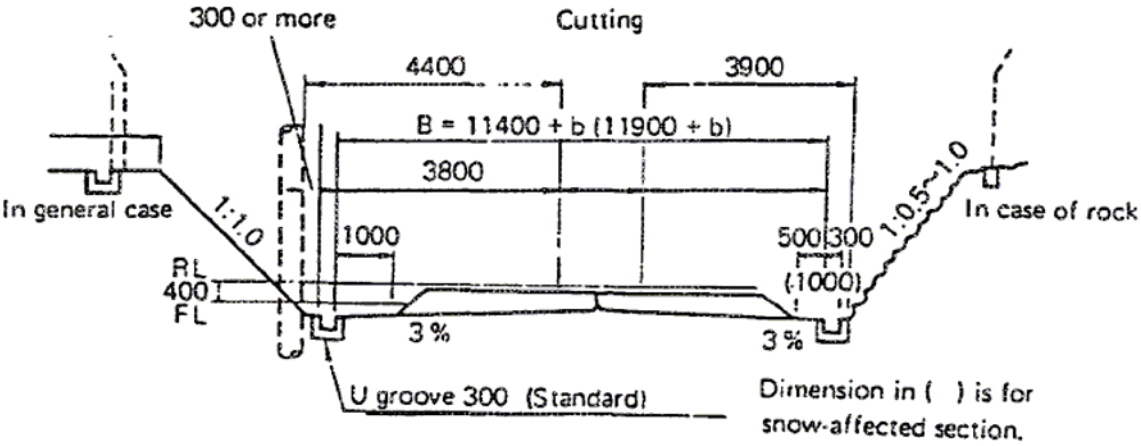

Figure 28. Japanese infrastructure construction standards with respect to winter[13].

In this investigation a few other solutions have been proposed, but these are not considered quite appropriate from either a winter or a high-speed perspective. Therefore these measures are only briefly described:

- The track can be raised above the ground so that snow blows away more easily.
- Snow can be melted by water. Figures 29 and 30 give examples of designs of this kind of system.

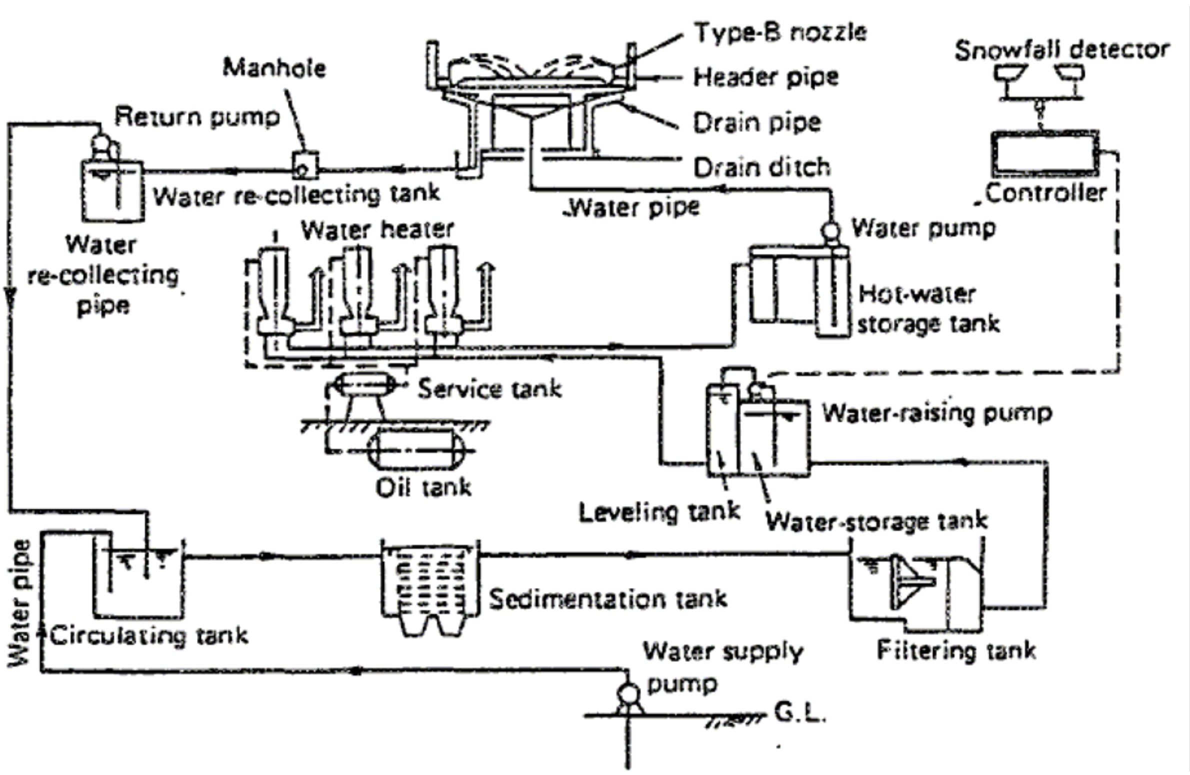

Figure 29. Outline of a Japanese water sprinkler snow melting system[14].

[13] Taniguchi, Mamoru (1992). *High Speed Rail in Japan: A Review and Evaluation of the Shinkansen Train*. California: The University of California Transportation Center, Working Paper UCTC No. 103

Figure 30. A Japanese water sprinkler system in practice[15].

3.3.2 TUNNELS

As already mentioned above in section 3.3.1 Snow clearing, tunnels can cause difficulties at winter. This has to do with both the narrow space which is often the situation in tunnels and the tunnel climate. It is often warmer inside tunnels causing snow and ice to fall off trains. Together with various water leeks the snow and ice that are being dragged inside by trains, make the forming of ice accumulations very common. The ice can cause trains to derail but also to collide with icicles which for example could damage the pantograph.

Winter problems in tunnels are today only managed with one solution:

- Clear tunnels from ice and snow – both along the track and the overhead wire.

3.3.3 FROST IN THE GROUND

Frost in the ground can either move the track or cause other track irregularities which influence a train's running dynamics. Derailments due to a frozen ground are on the other hand very unusual. This perhaps as the process were frost in the ground causes track irregularities is very slow and the problem can be discovered before the situation becomes critical.

High-speed tracks consist of better infrastructure with a well drained ground and therefore the problems with frost in the ground are rather rare.

3.3.4 TRACK STIFFNESS

To keep the track stiffness within the specified limits is of great importance for the running performances. The following winter problems have been identified in this study:

- The track gets stiffer when the embankment is frozen and the increased track stiffness may cause increased wheel-rail forces. It may affect train and track maintenance as well as the passenger comfort. The situation may become worse at increased train speeds.

[14] Ibid.

[15] Volcano's web page. Available: http://www.volcano.co.jp/english/frame/index_p.html (2006-05-08).

- The rails get more brittle when it is very cold and accordingly more sensitive to damages from for instance wheel flats.
- The friction on the rail increases with reduced humidity, which normally is the case during the winter season. Hence if grease is added to the rails also in the winter time it reduces the wheel and rail wear.

3.4 SWITCHES

Problems due to malfunctioning switches are the most common reasons for disturbances during the winter period. In the Nordic countries special snow protections have been mounted in switches to reduce the amount of snow that gathers and to keep the area between the tongues clear. Unfortunately, the protection can not fully cover the movable parts.

With higher train speeds it has been obvious that the snow protections do not function properly. They break to peaces and/or parts come loose. This is due to both the ice that fall off the train and hit the covers and the strong air streams under the passing train.

The number of covers in use has been reduced in recent years especially on lines with high-speeds. This action is also motivated by the fact that trains running in higher speeds clear the track from snow better.

Winter problems with switches can be categorised as follows:

- Problems related to snowfall, snowdrift etc.
- Frozen parts in the mechanism
- Blocked movements
- Maintenance

3.4.1 PROBLEMS RELATED TO SNOWFALL, SNOWDRIFT ETC.

In the Nordic countries, all major switches are electrically heated to melt the snow that gathers along the two rails. In long high-speed points, as much as 40 kW can be needed for heating the main rails for the length of the two tongues and the movable crossing.

In order to reduce the problems with the switches a number of preventive measures have been proposed:

- Make sure the mounted heating equipment is optimized and functioning.

  The heating shall only be turned on when needed, automatically or manually. Having it on all the time results not only in high energy costs but also that there will be too much water that will freeze in the ballast and cause problems.

  Together with the weather forecast and local weather measurements the best automatic switching-on is accomplished. On manned stations there shall be a possibility for the station staff to activate the electric heating of the switches as desired. An example of when such an extra need occurs is when there are cross winds.

  Only the heating itself cannot clear the switch in very heavy snowfall. Manual or motorised brushing will also be needed. It is recommended to clear the whole switch from snow as well as some 20 m on both sides of it.

  It must be considered how many kilowatts that shall be installed in a switch and the costs for the energy compared to the need of having it functioning regardless of the weather. An alternative can be to allocate maintenance people to critical switches during times of operation. However this means blocking the line as long as manual work is being done in the track.

- Make plans how to operate the line with just a small number of the switches in function.

  During snowfall it has become clear that it is better to use a smaller number of points more frequent and let the rest be untouched. The latter shall then normally lay in the main direction.

- Mount some type of stopper along critical points for the wind borne snow such as snow fences or some type of spoilers. Below these installations are detailed.

SNOW FENCES

Along line sections with frequent harsh snow conditions often snow fences or snow sheds are mounted, compare figure 27. This can also be done at places where there are important points.

RUBBER SPOILERS

Tests have been made with a rubber spoiler along the main rails for the length of the tongue, see figure 31. The spoiler is mounted outside the rails to a level some 100 mm above top of rail, which can be accepted as the material is rubber.

The spoiler is supposed to lift the snowdrift so that snow will not fall between the tongue and the main rail. The protection does probably only work for cross-winds. There is also a cover under the spoiler to insulate the heated rail on one side for the cooling effect from cross-winds. The evaluation is yet not completed.

Figure 31. Skutskär. The rubber spoiler as well as the cover outside the rails is shown, see also figure 31. Notice that there are double motors for altering the switch.

V-FORMED SPOILER

Information has been received that a V-formed spoiler has been used in Finland in front of switches as a spoiler to reduce the amount of snow that gathers there. More details of this as well as eventual effects are not known at present.

BRUSH SPOILERS

Tests have been made with long brushes along the outside of the main rail, see figure 32 that follows. As far as known the effects are the same as with the rubber spoiler. The advantage by using double brushes is that the lower brush isolates the heated rail on one side and reduces the cooling effect from cross-winds. The height of the double brush is some 300 mm.

The tests are performed in Sweden with help of a brush manufacturer. The results are not known today.

Figure 32. Detail of a brush spoiler is seen to the left. To the right the mounting outside the main rails in a switch is shown.

3.4.2 FROZEN PARTS IN THE MECHANISM

The mechanism for an electric driven switch consists of the switch motor, the interlocking, the manoeuvring rods and the contacts for positioning check. All these mechanical movements must function or the switch will not be able to turn. Therefore:

- The motor sealings must be fit for purpose. Water must not come into the motor mechanics.
- The drainage around the motor and the rods must function all year around.

  The rods used for manoeuvring the tongues or the switch motor tend to freeze when melting snow gathers and the drainage around the rods is not sufficient. This can be the situation when the temperature often changes from plus to minus. Then the ground cannot take care of more water, which stays and thereafter freezes.

  There have been discussions about the possibilities to heat the ballast around the rods and the motor where the problem often occurs.
- The positioning contacts must be hindered to freeze as well as they must function also in severe winter conditions.

  If the positioning contacts in the switch freeze, the position of the tongues can not be controlled, see figure 33. If the switch position is not known, the Swedish rule is that it must be closely examined by the train driver and speed is restricted to 10 km/h.

Figure 33. A switch with rubber spoiler and covers outside the main rails. The contacts for positioning control of the tongue can be seen next to the far tongue.

3.4.3 BLOCKED MOVEMENTS

The movement of the tongues can be blocked for various reasons. The most common reason is that ice and snow falls off a passing train when running over points. Just at the crossing the trains rattle a little and the ice and snow falls down, often between the tongue and the main rail of the points. When the train is approaching a station the brakes may be used and heat being generated in the bogie and underframe, causing ice and snow to melt. Thereto, in bigger cities the temperature is usually higher than in the countryside. This helps the ice and snow to get loose and fall off.

As the contact zone between the piece of ice and the main (heated) rail is very small, it takes a long time to melt the ice. These blockings can in the short term only be removed manually. In bigger stations with staff available, this can be arranged. Out on the lines it can almost only be done with help of the driver who has to stop in front of the switch, get out, remove the obstacles and then continue the journey. For all trains this is most time consuming.

3.4.4 MAINTENANCE

To reduce the winter problems the following has been proposed:

- The electrical heating must be checked before each winter period.
- Lubrication of points must increase in the winter time. The heating has the effect that more lubricant is necessary.
- The small length movements in the track must be observed and the correct distances to the rods must be kept.

  A passing train generates small movements of the track. These movements in the ballast can give as a result that the rods for a switch comes too close to a sleeper. Then there is a risk that they freeze to the sleeper and the switch motor can not move the switch fully or at all.
- The supervision of important switches must improve.

  Data supervision has been tried on a number of switches by measuring the current to the switch motor, see figure 34. In a switch that moves rather sluggish, the current increases and the maintenance people can get the information direct to their mobile telephones. A slow motion is often the pre-stadium to not working at all. The results so far are very promising.

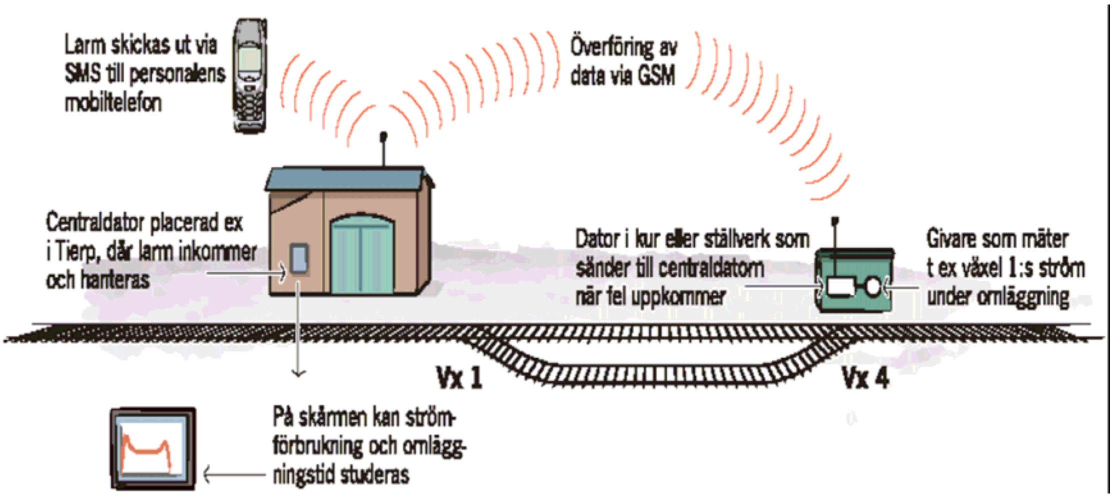

Figure 34. The computer measures the current and the time for manoeuvring a switch. If the result not equals the expected value a warning signal is sent out directly to the maintenance people's mobile telephones[16].

3.5 PLATFORM TRACKS

Besides being hard to clear from snow, another problem related to platforms is that trains drop ice and snow on the track when stopping. Ice and snow fall off the trains due to increased temperature in the bogie and underframe. Brakes, which have been heated at stopping, dissipate heat. The train's equipment is not cooled by the wind. Some platform tracks are warmer than the line.

When another train passes the platform at higher speed, ice on the track can be thrown up on the platforms and harm passengers. With higher speeds this problem is likely to get worse. The next figure 35 illustrates a rather normal condition on a main station platform track.

[16] (2006). *Förebyggande övervakning – FÖSA*. Information brochure, The Swedish National Rail Administration (Banverket Produktion).

Figure 35. A platform track with a lot of ice that has fallen of stopping trains.

The problem has been proposed to be dealt with through the following actions:

- Prevent trains from accumulating snow (see chapter 2.2 Snow packing for further information).
- Decrease the speed at platforms.
- Separate high-speed tracks and platform tracks.
- Improve the track clearing at platforms.

3.6 OVERHEAD WIRE

The overhead wire or catenary is a sensitive component in itself and winter makes the situation even worse. It is more common that the overhead wire is torn down wintertime compared to other seasons.

A torn down overhead wire can be the outcome of several situations or combinations of these. Nearby trees that carry heavy loads of snow can for instance fall over the wire and subsequently tear it down. Most other causes have to do with passing trains and the contact with the pantograph of which a few influencing factors follow:

- Through excessive wear, which could be the result from arcing, ice or rime on the overhead wire can damage the pantograph, which next can tear the catenary down.
- The catenary is extra vulnerable at points where the wire is changed into another one. During wintertime these locations become even more sensitive and if a train with a damaged pantograph passes there is risk for tearing down the catenary.
- In cold climate the overhead wire can not move as easily as usually. This has to some extent been solved with heavier weights that modify the tension conditions. However it is possible that the overhead wire is not in its right place and a passing train can then rip the overhead wire down.

- In coldness practically all movements get harder and more difficult. For example the pantograph may not have the same suspension characteristics all year around. Deviations and imperfections therefore get of larger importance during winters.

Another problem occurs when ice build up on the overhead wire. Ice makes the wire heavier and hinder current conduction to the pantograph. This can cause speed restrictions and power failures.

Besides keeping the pantographs in good conditions the following measures have been proposed in order to increase the catenary's winter durability:

- Heat the catenary.

  It could be necessary to heat the overhead wire at some locations during extra tough weather conditions. Sometimes it is sufficient with the heat generated by the traction current why a frequent traffic is preferable from this aspect. Sometimes an additional reactive current is used to prevent or reduce the build up of rime on the contact wire.

- Measure and forecast ice accretion on the catenary.

  By the use of geographical information systems the ice build up can be both measured and forecasted in time for preventive maintenance. Data from the system can also be of help for planning of maintenance operations.

- Have the area next to the track well cleared.

  Trees close to the track should be removed in order to prevent them from entering the free space when they are burdened with snow and ice. It is also preferable that stations are not designed with roofs that lead snow and ice towards the catenary.

3.7 BALLAST PICK-UP

Trains running at high speeds can make macadam stones lift from the ground. These stones can cause damage to whatever gets in their way. When a stone hits a running train, it receives more energy. An avalanche effect is created if the stone hits the ballast and causes other stones to lift. The damage caused to the train can be most expensive to repair. Ballast stones can of course also be thrown sideways and collide with for example other trains, buildings or still worse, human beings.

The phenomenon of ballast pick-up is not fully understood yet. Amongst others is it caused by snow and ice that fall off the train and hit the ballast which starts the process. Besides this the lifting of ballast is believed to be influenced by;

- the underpressure just behind the front or the rear of the train,
- a sail-effect caused by ice and snow located on top of the ballast,
- vibrations due to train passage that reduce the friction among the rocks and make them lift easier and
- whether the macadam is frozen or not – a frozen track may reduce some ballast pick-ups.

In Japan, ballast pick-up is reported to be a problem for a very long time. The literature study carried out suggests that ballast impacts as a consequence of trains dropping ice and snow is one of the largest winter problems in Japan. The following quote shows this and a Japanese approach to solve the problem.

"*One unexpected problem started with a heavy snowfall at Sekigahara (between Nagoya and Kyoto) in December 1965. Shinkansen trains running through snowfall at very high speeds blow up the snow on the track. The blown snow sticks to the underfloor equipment and freezes rapidly into ice. When the train enters a warmer region, the frozen ice thaws and drops at high speed from the train causing the ballast to fly up and seriously damage the underfloor equipment. There was no immediate solution other than reducing speeds to 70 km/h in snow. Later, water sprinklers were installed along the track in order to melt the snow, but speeds in snow are still restricted even today (although not as low as 70 km/h in most cases), because excess water sprinkling can damage soil embankments. Drawing* *lessons from this, the Joetsu Shinkansen, which runs through a very snowy region north of Tokyo, was built entirely on concrete viaducts and large amounts of warm water are sprinkled during snowfall*."

(Saito 2002)

There have even been Japanese reproductive tests of thrown ballast in order to clarify the actual conditions of the phenomena. The behaviour of ballast being struck by ice and snow blocks at high speeds was revealed. Figure 36 holds pictures of this test.

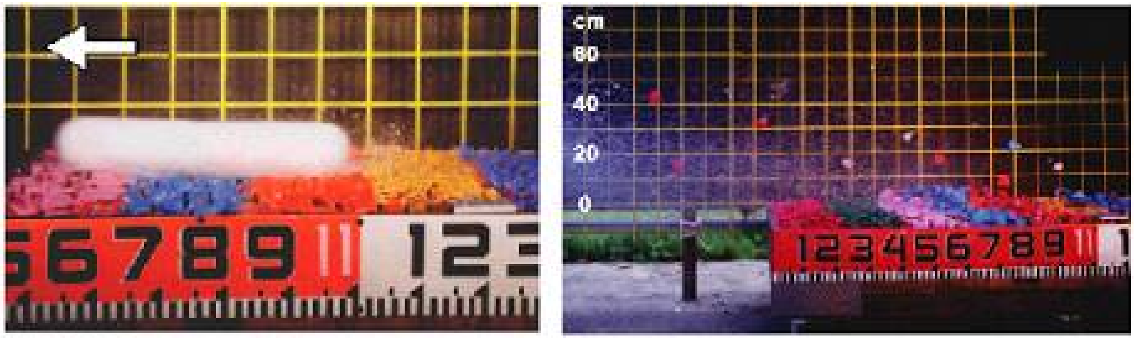

Figure 36. Japanese reproductive test of ballast flying phenomenon[17].

The test clarified the relationship between the number of thrown ballast stones and the mass and speed of the snow and ice hitting the track, this is described in figure 37. In this figure the numbers of stones thrown higher than 33 cm are of importance as this is the distance from the ballast to the train's underframe.

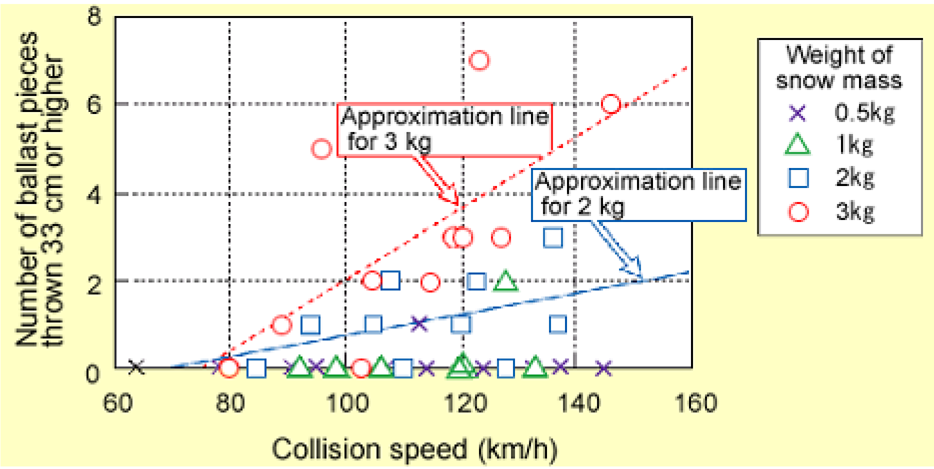

Figure 37. Relationship between collision speed of snow/ice mass and number of stones thrown 33 cm or higher[18].

Ballast pick-up is assumed to increase with the train speed. At speeds above approximately 160-180 km/h an increasing tendency for ballast pick-up has been noticed. The higher the trains speed the higher:

- energy of the snow and ice blocks that fall off the train,
- energy of stones ricocheting between train and track and
- underpressure and air turbulence under the train.

[17] Railway Technical Research Institute, Tokyo Japan (2004). *Clarification of Phenomenon of Ballast Thrown up by Snow/Ice Falling from the Train*. (Electronic) Available: http://www.rtri.or.jp/rd/openpublic/seika/2001/01/safety_E02.html.
[18] Ibid.

Ballast pick-up and its affects can be limited through following measures:

- Lower the macadam level.

  In Finland, Norway and Sweden the macadam level has been lowered approximately 3-5 cm under top of the sleeper. The lowering is not done from aerodynamic reasons but primarily for letting the falling ice and snow crush against the sleepers' concrete edges. Lowering the macadam level has in fact proven to be very effective for speeds up to 200 km/h and has led to the situation that some people do not consider ballast pick-up a problem any longer.

  Even if the lowered ballast level has been proven successful, higher speeds can raise problems again.

  In Germany the ballast level between the sleepers has also been lowered, however speeds are reduced to 200 km/h at some extreme weather conditions.

- Reduce the train speed.

  As already mentioned this is the procedure in Germany but also in France. However in these countries this is an action only necessary during a few days per year. In the Nordic countries this is not considered an acceptable solution.

- Decrease the distance between sleepers.

  This is a theoretical measure that follows the same principle as a lowering of the macadam level.

- Make the underside of the train as flat as possible.

  The underpressure below the train can be reduced if the train's underframe is designed as flat as possible. However, bogies and ploughs will always create turbulence under the train.

- Apply train designs that accumulate as little ice and snow as possible.
- Strengthen areas subjected to ballast pick-ups, see chapter 2.3.1 Wheels, axles and axle boxes.
- Cover the ballast with a net.

  If the ballast were kept in place with some kind of net stones could not lift. This measure is frequently used in eastern Japan.

- Use ballast-free tracks (slab-track) for high-speed trains.

  Slab-track is considered to be the most effective solution. However, slab-track is considered to have disadvantages compared to ballast track. It is for example much more expensive and makes maintenance more difficult.

- Apply heat to surfaces on the train that accumulate snow. See chapter 2.2 Snow packing.
- De-ice trains from packed snow and ice.

3.8 TRACK CAPACITY

The track capacity becomes even more critical wintertime when the track and rolling stock are burdened with winter problems. As already mentioned it is for example hard to clear tracks from snow when there a few alternative tracks and no vacant capacity. In traffic systems where different train services share capacity, high-speed trains can also be disturbed.

With high utilisation of the tracks the traffic system gets vulnerable to disturbances, which will be the case in the winter months. Consequently more tracks are needed especially on locations where traffic volumes are close to the capacity limits. It has been proposed to:

- Reduce the number of trains during at least a part of the winter period.

4 CONCLUSIONS

Winter has not proven to be a question of high priority all year around. This can for example be understood from the fact that;

- winter causes problems every year and sometimes even seem to come as a surprise,
- mild winters tend to get actors within the railway sector to more or less forget about large parts of the winter problems,
- winter solutions are often acute, regional and of short-term.

In order to facilitate the winter problems an exhaustive responsibility together with a more long-term perspective on the winter questions is required.

Above this, the performed investigation implies the following:

- At some winter conditions all types of brake forces cannot be guaranteed. Winter can either entirely or partially put the brakes out of function. This could get the most severe consequence which increase with the speed. The problem also leads to uncertainties regarding how the emergency brake should be handled.
- There are a few general rolling stock winter problems - however the majority of the problems are vehicle specific. This especially concerns electrical multiple units with or without carbody tilting.
- Ballast pick-up by falling ice blocks is a big winter problem that has not been solved.
- There is not sufficient de-icing capacity in order to secure necessary rolling stock maintenance in time without risk of disturbing the train operation.
- When it concerns high-speed services above 200 km/h in winter climate there is a large uncertainty in Scandinavia as those kinds of winter experiences do not exist. The high-speed winter problems and their affects are therefore not yet fully understood. Experiences of the higher speeds exist in Europe, but not in combination with Scandinavian winters.
- Contacts taken indicate that speed restrictions wintertime are rather common in other European countries – both France and Germany lower the speeds if the winter climate demands it. This leads to the conclusion that there are high-speed dependent winter problems that cannot be managed in these countries today.
- European standard designs are not always practically applicable during Scandinavian winter conditions.
- Winter puts high requirements on the rolling stock why the competence of the purchasing organisations, as well as in the supply industry, is of great importance. Many winter problems can be prevented during the design phase.
- Apart from this project, with the research program Gröna tåget, there is today no collective research in Scandinavia that concerns winter. NUP-T1 of the former CNR (Community of Nordic Railways) of 1997, is the latest Nordic winter project identified. Today, most progress is made in separate fields within the industry either locally by smaller entrepreneurs or by rolling stock manufacturers that regard winter knowledge as a competition advantage.
- As regards the rolling stock design it is in some situations a question of priority; either good maintenance possibilities or good winter durability. For example the bellows that the Swedish X2000 were fitted with, the brake disc covers and other kinds of winter protections can sometimes complicate maintenance and visual inspections.

5 PROPOSALS FOR FURTHER STUDIES

The main proposal for further studies is to examine future requirements of the Swedish railway sector in order to perform high-speed train services without speed and operation restrictions due to winter conditions. This ought to be reflected by the following proposed questions at issue:

- Which are the winter problems for speeds above 200 km/h and how can they be managed?

  This investigation has mainly covered the Nordic countries and their experiences. Thus, experiences above 200-210 km/h are mainly missing. The study needs to be expanded to countries were the speeds are higher.

  Based on this study, the following preliminary list of issues has been made up, where specific development efforts as regards speeds above 200 km/h need to be done:

  - Running dynamics, see chapter 2.3.4
  - Disc brakes, see chapter 2.4.1
  - Collisions with animals, see chapter 2.6
  - Pantograph, see chapter 2.9
  - Ballast pick-up, see chapter 3.7

- Would it be relevant to reduce traffic production, e.g. reduced train speeds, in Sweden at severe winter conditions?

  It is a well established praxis in Sweden not to differentiate winter from summer as regards the traffic production and time tables. Train speeds are expected to be the same all year around. This is not the situation in some other European countries – not even always in Japan. It is therefore of relevance to investigate why speed restrictions due to winter occur in some countries and if this or other reduction of traffic production could be a scenario also in Sweden.

- Are further authority demands concerning winter required for high-speed train operation?

  Since high-speed train operations above approximately 200 km/h during winters is an unknown area in Scandinavia today there is a possibility that further requirements need to be defined. Are, for example, the present processes for verification sufficient as regards winter?

- Are there standards that need to be modified or added to take account of Scandinavian high-speed winter requirements?

- Specifications and guidelines for design and purchase of rolling stock and infrastructure components considering winter conditions need to be drawn up.

  An up-to-date independent rolling stock specification containing winter aspects does not exist at the moment.

- Is another winter organisation needed for high-speed train services?

  The present winter organisations do not always manage winter issues at a sufficient high level. This give rise to local decisions of and among operators, infrastructure managers and maintenance actors. Compared to present winter routines, high-speed operations may demand another management.

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