Climatic Wind Tunnel Vienna

Functional Tests for Increasing the Reliability of Rail Vehicles

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Quality in any weather

RAIL TEC ARSENAL

Functional Tests for Increasing the Reliability of Rail Vehicles

Taking into account passengers' expectations about ticket price, travel time and quality is a key to success in rail transport. Modern rail vehicles must therefore meet high demands in terms of safety, reliability and comfort.

Climatic wind tunnels allow weather conditions to be simulated realistically in order to carry out meaningful climatic tests on complete rail vehicles. These tests are currently exclusively used for verifying the proper functioning of individual components according to vehicle operator specifications and for analysing problems once defects have been detected during service operation.

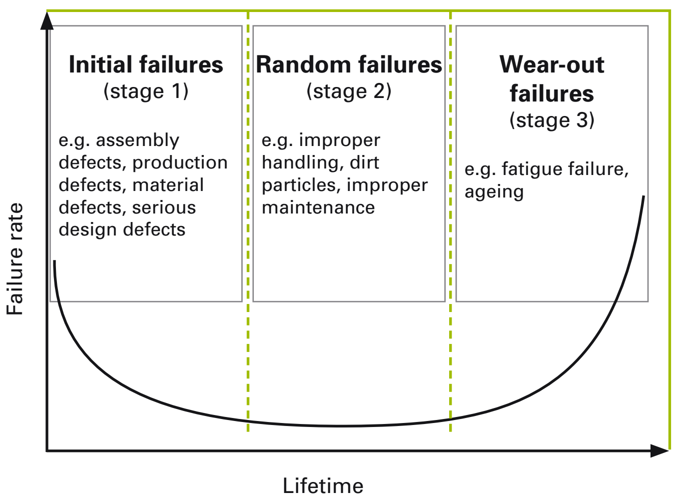
The opportunity to carry out tests with the aim of minimising cost and risk is taken only in exceptional cases. This article will show that tests in a climatic wind tunnel can make a valuable contribution to reducing the risk of malfunctions during operation, thus increasing vehicle reliability.

What is reliability?

According to [1] reliability is defined as the probability that a product does not fail within a defined period of time under given functional and environmental conditions.

The life cycle of technical systems is characterised by a failure behaviour known as the „bathtub curve" (cf. Figure 1). Failures at the beginning are due to assembly or design faults, resulting in a low reliability of the system early in its life cycle. Once these defects are eliminated, the failure rate decreases to remain at a lower constant value throughout the useful life of the system. These failures result from improper handling and maintenance and initial defects that have not been remedied. The failure rate then again increases towards the end of the life cycle due to wear and fatigue.

Figure 1: Failure rate „bathtub curve" according to [1]



Reliability has a direct effect on availability, which according to [1] is defined as the probability that a system is functional at a particular point in time or during a defined period of time, if it is properly operated and maintained.

Frequent maintenance may lead to a high reliability but at the same time reduces availability. As a general rule, however, improved reliability usually goes hand in hand with an increase in availability.

A comprehensive quality assurance programme is required in order to be able to guarantee a „specific" reliability. The standard EN 50126 „The specification and demonstration of reliability, availability, maintainability and safety (RAMS)" specifies such a programme for rail vehicles and also requires the proper functioning of all systems to be demonstrated under the specified climatic conditions.

Although many components are individually tested by the manufacturer, some defects do not occur until the component interacts with other parts of the system. The proper functioning of all components must therefore be tested systematically under critical climatic conditions. These functional tests allow a predicted reliability to be demonstrated under extreme climatic conditions.

Reliability in practice

„Everybody talks about the weather. We don't". Some decades ago, the German Railways used this slogan to demonstrate that travelling by train is comfortable and takes you to your destination in time in any weather – in contrast with the passenger cars of the time.

And what is the situation today? The passenger car has long caught up in terms of comfort, whereas many commuters know from experience what it is like to wait for a delayed train on a cold winter's day. The lack of reliability of rail vehicles under specific climatic conditions is one of the main reasons for delays and disruptions of rail service. Extensive climatic tests of all components help to detect and eliminate any potential defects prior to service operation.

Efficient and effective climatic tests require detailed knowledge of the components' susceptibility to failure under specific climatic conditions. However, the standardised failure records of the railway companies provide only limited information on this point. In a diploma thesis [2] carried out at Rail Tec Arsenal, the climate induced failures of vehicle components and systems were therefore investigated based on a detailed survey of rail operators and rail vehicle manufacturers.

Figure 2 shows the failure rates of different vehicle components as one of the results of the study.

Figure 2: Failure rate of different components according to [2]

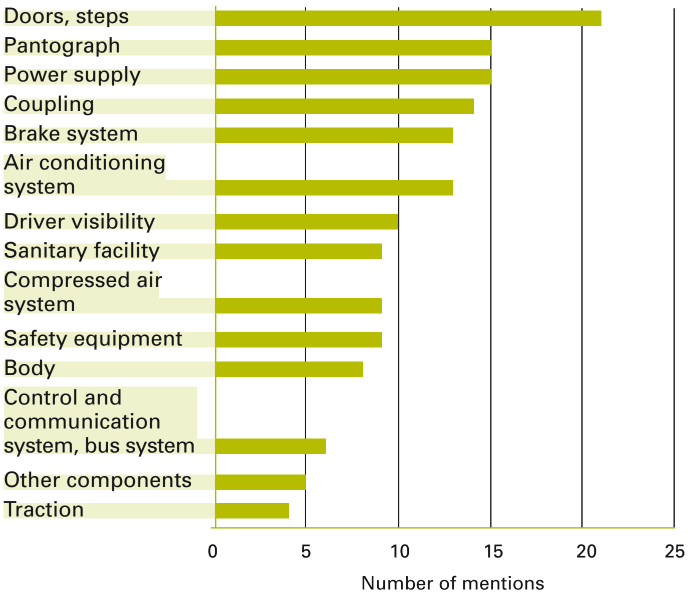


Figure 3 shows the relevance of different climatic conditions for different components. For example, summer conditions with high temperatures and humidity levels are more critical for the converter or air conditioning system than winter conditions, while malfunctions of the pantograph and warning horn are exclusively caused by winter conditions.

Figure 4 shows the results of another survey on the failure rate and relevance of individual components, which was conducted among 80 railway experts at the international workshop on „Climatic tests to increase reliability of rail vehicles" in Vienna in September 2005. While the results in terms of failure rate distribution are similar to the survey results obtained by [2], it is interesting that the relevance of practically all components listed was rated as high. This clearly illustrates that experts are all painfully familiar with the problem of reliability under specific climatic conditions.

Figure 3: Relevance of different climatic conditions for different components according to [2]

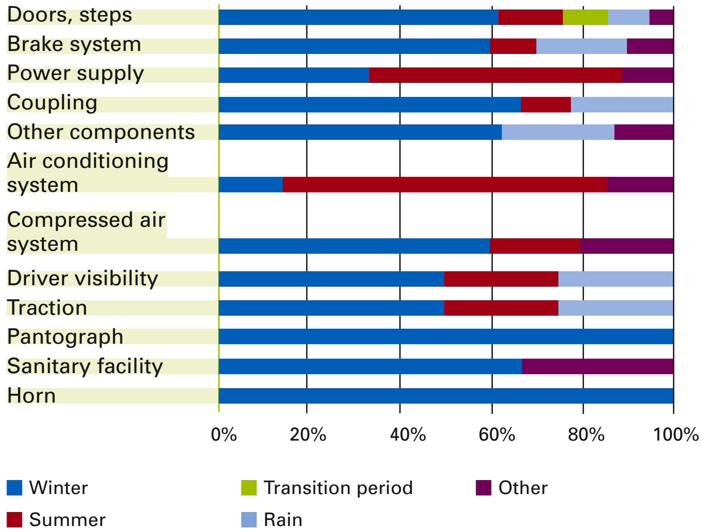
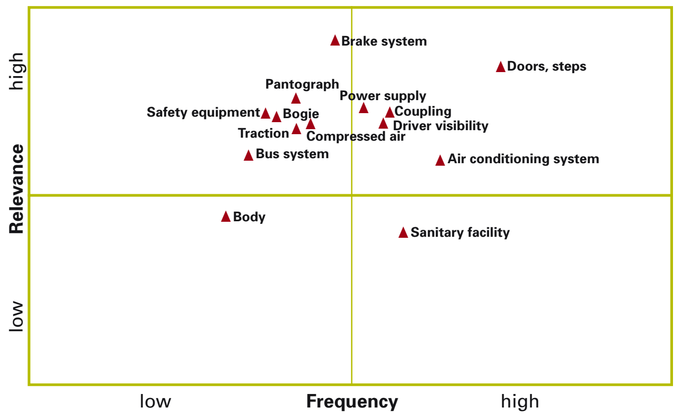


Figure 4: Relevance vs. frequency of failures of different components according to [3]



Climatic conditions

Both the critical operating states for specific components and the natural climatic conditions must be taken into account in order to be able to carry out functional tests as realistically as possible.

The two standards EN 50125-1:2000 „Environmental conditions for equipment, Part 1: Equipment on board rolling stock" and EN 60721-3-5:1998 „Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities; Section 5: Ground vehicle installations" define and classify the environmental conditions for different climatic zones and types of application.

While the limit values specified for temperature, relative humidity, wind speed, solar load and rain can be used as reference values for functional tests, the standards do not define the actual critical climatic conditions, i.e. the interaction of several individual parameters and detailed climate scenarios for specific functional tests.

For example, EN 50125-1 defines a precipitation amount of 6 mm/min for rain and requires the influence of wind and vehicle movement to be taken into account. It gives a precise definition of „actual“ rain for functional characteristics like the water resistance of components or windscreen wiper performance. At high rain rates, however, driver visibility is also strongly affected by fogging on the inside of the windscreen at high exterior temperatures and humidity levels.

EN 50125-1 also gives general information about snow, ice and hail. It states that the influence of all possible forms of snow and/or hail must be taken into account and points to the fact that large amounts of powder snow may get into the vehicle, where it melts and may freeze again during periods of standstill. The rear cars of a train are the most seriously affected by this problem. The standard also states that the influence of forming or falling ice must be taken into account for all equipment installed inside and outside the vehicle.

These general instructions are important and correct, but in no way define critical climatic conditions for functional tests on components. In future standards, these conditions should be specified more precisely.

Functional tests

Functional tests are designed to simulate both operating states and climatic conditions in order to identify potential problems, such as constructional defects or unexpected interactions between components and systems. The definitions of „type test“ and „verification“ in the relevant standards correspond most closely to this meaning.

EN 50215 defines a type test as a test of one or several devices, a system or a complete vehicle in order to demonstrate that the design complies with the required specifications and relevant standards.

EN 50126 defines verification as confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled.

Classification in terms of climatic conditions

Practically all rail vehicle components can be subjected to special functional tests under extreme climatic conditions to test the reliability of the systems. These tests can be divided into the following categories according to the climatic conditions required:

- Extreme temperatures and humidity levels have a negative impact on mechanical, electrical, electronic and pneumatic components.
- Rain and wind ingress, notably via the connecting corridors, doors and windows, gives an indication of leakage. It is also important to test the proper functioning of the windscreen wipers.
- Wet snow has an impact on all mechanical components subject to outside conditions, such as doors, steps, couplings and roof equipment.
- Ingress of dry snow into air intakes and gaskets often leads to problems.
- Ice formation on mechanical components, such as pantograph, circuit breakers, doors, steps and couplings causes malfunction or blocking of the subsystem.

Quasidynamic testing

In order to obtain meaningful results, however, standstill climatic tests alone are not sufficient, since it is essential to simulate not only the weather conditions but also the movement of the vehicle. The climatic wind tunnel is therefore equipped with a fan for wind simulation and a roller dynamometer. The two-axle dynamometer has one driven axle to measure the traction or braking forces transmitted. This allows the wheel force curve to be measured as a function of the driving speed, taking into account the power consumption of auxiliary units in specific operating states.

Advantages over braking tests on a friction test rig include real rail/wheel contact, precise simulation of wind, snow and ice conditions and the ability to test the entire vehicle together with its major components [4].

The design and testing of the cooling system is another essential aspect in diesel vehicles. The objectives of various system tests on the dynamometer are specified in more detail in [5]. The combination of climatic wind tunnel and dynamometer allows both environmental conditions – temperature, humidity and solar radiation – and mechanical loads to be simulated realistically [6]. Wind simulation also plays an important role in providing a realistic simulation of flow conditions at the specific cooling unit.

Experiences from practice

Climatic tests help to demonstrate the reliability of rail vehicles prior to delivery. Any defects detected can usually be eliminated during the tests with comparably small effort. The advantage of this approach is that the measures taken can be tested immediately for their effectiveness under the same conditions.

Since defects are detected in practically every test, the effort of climatic tests is worthwhile. Every defect identified prior to roll-out reduces the number of initial failures, saves expensive and time-consuming repairs, and prevents malfunctions and additional costs during service operation.

Examples from practice:

Vehicle body

Insufficient insulation and/or leaks in the vehicle body often have a negative impact on interior temperatures and may cause condensate to form in the passenger areas or driving cab. In the case of low outside temperatures, this may cause the floor surface temperatures in the vestibules to fall below the freezing point, leading to ice formation and thus even posing a serious safety risk.

The causes of these problems can be identified in the climatic wind tunnel: leaks can be located on the basis of smoke and wind simulation, while insulation problems of the vehicle body, doors, windows, corridors etc. can be identified using a thermography camera.

Doors and steps

Accumulations of ice and snow in the door area obstruct or even prevent opening, closing or automatic reversal of doors and may cause retractable steps to become stuck.

Some targeted design modifications or improvements in the control system are often sufficient to eliminate these problems or improve the situation. These measures can be investigated and tested efficiently under reproducible snow and ice conditions.

Windscreen and side windows

Insufficient functioning of the windscreen heater or air inlets at the windscreen and/or side windows of the driving cab may cause them to mist up. Snow and ice build-up impairs visibility and may lead to complete failure of the windscreen wiper.

Poor adjustment between the windscreen washer, wiper and heating systems and the air conditioning unit of the driving cab may be one possible reason for this. Adjustment of the settings under different climatic conditions usually provides effective solutions for such problems.

Bogie with brake system

Bogie components such as dampers, sanding, tilting and brake systems are safety relevant components, which must not fail even under the most extreme environmental conditions. These components are usually very exposed and therefore prone to the accumulation of snow and ice. The possible consequences may range from partial malfunction to complete failure, as in the case of ice build-up on the sanding system.

All these environmental conditions acting on the underframe components can be realistically simulated on the dynamometer in the climatic wind tunnel. The measures taken to reduce these problems, such as fitting a heater or housing to the sanding system, can be subsequently tested for their effectiveness.

Power supply and on-board electronics

The entire power supply system of a vehicle – e.g. pantograph, main switch, transformer, converter, battery, and on-board electronics – must also function reliably under all climatic conditions. Both low and high temperatures combined with high humidity typically lead to problems with electronic components. Ice build-up usually causes additional mechanical problems with the pantograph.

Climatic wind tunnel tests allow these problems to be identified and remedied in good time.

Air-conditioning system

The air-conditioning unit is not a safety-relevant component, but any malfunction or failure has a negative effect on passenger comfort. Even at extremely high temperatures (above the design point, e.g. 35°C and 50% relative humidity for Central Europe) the control unit may only turn down the air-conditioning system, but never turn it off completely. The air-conditioning system must also ensure sufficient fresh air supply.

Climatic wind tunnel tests are practically indispensable for adjusting air distribution within the vehicle to different loads, for optimising the control system and for demonstrating system capacity.

Conclusions

The functional tests described above show only a few examples from practice. The following table gives a more detailed overview of typical functional tests on different components, together with a short description of the failure scenarios, climatic test conditions and functional requirements.

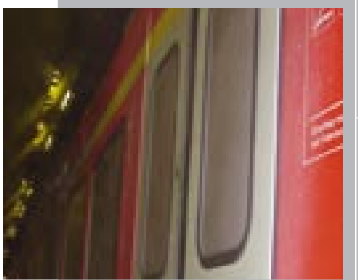
Detailed instructions on how to carry out and evaluate these functional tests ensure a high degree of standardisation and comparability. Feedback from regular service operation is indispensable for developing additional functional tests under critical climatic conditions and for continuously evaluating the effectiveness of these tests.

Functional tests in a climatic wind tunnel make a substantial contribution to reducing the risk of failure during operation and increasing the reliability of rail vehicles in all weather conditions. Testing practice has repeatedly shown the necessity of testing the entire vehicle, for even the best component inspection is no guarantee for the proper functioning of that component within the vehicle.

The biggest advantage of climatic wind tunnel tests is that the climatic conditions can be exactly reproduced so that any improvements made can be immediately verified – this saves time and money.

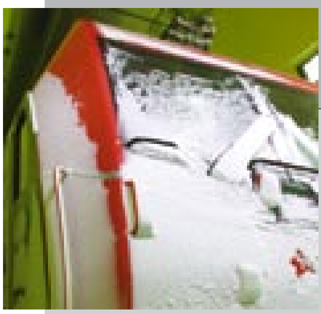
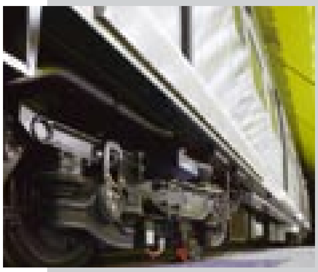
Function tests on different components relevant for reliability

Component	Problem	Climatic conditions	Requirements
Doors, steps	Malfunction due to ingress of snow and subsequent thawing and freezing processes	Dry snow Temperature: -20°C Wind: up to 100 kph Duration: 30 min (vehicle in regular operation).	▸ No snow accumulation inside the vehicle ▸ Door and steps open and close completely ▸ Closing forces, obstacle detection etc. in compliance with EN 14752
	Malfunction of opening and closing mechanism due to ice build-up	Ice Ice thickness: 1-2 mm Temperature: -20°C Hardening 10 min (vehicle switched off)	▸ Door and steps open and close completely ▸ Closing forces, obstacle detection etc. in compliance with EN 14752
	Malfunction of step due to snow accumulation and freezing processes during drive cycle (with station stops)	Application of wet snow layer on extended step Snow layer thickness: approx. 2 cm Compacting Simulated drive cycle with step retracted Temperature: -10°C Duration: 15 min. Cycle is repeated at least three times	▸ Step can be extended and retracted ▸ Step detects obstacles and peak force is below 300 N on contact according to EN 14752. ▸ Step does not move when the door is fully open
	Malfunction of door control at extreme outside temperatures	Extreme temperatures / rel. humidity according to application range	▸ Door and steps open and close completely ▸ Closing forces, obstacle detection etc. in compliance with EN 14752
Power supply, Converter, Electronic network	Failure of converter at high outside temperatures and humidity levels	Cooling of converter to +5°C at high humidity Rapid heating to extreme conditions of application range - possible condensate formation	▸ Converter does not fail during 3-hour operation under extreme conditions ▸ No performance reduction of converter
	Malfunctions or alarm messages during start-up of electronic network under extreme climatic conditions	Extreme temperatures / rel. humidity according to application range	▸ No malfunctions or alarm messages during start-up of electronic network



Component	Problem	Climatic conditions	Requirements
Bogie, Brake system, Tilting system, Level control	Stopping distance increases due to snow build-up on brake system	Dynamometer test in wet snow conditions Temperature: -7°C Duration: 30 min Braking to standstill Cycle is repeated several times to examine the influence of further accumulation of snow and ice mixtures.	▶ Mechanical components are fully functional ▶ Stopping distance in snow conditions increases by less than 15 % according to UIC 541-3
	Malfunction of brake system due to ice build-up	Ice on all moving mechanical parts Ice thickness: up to 5 mm Temperature: -20°C	▶ Mechanical components are fully functional ▶ Brake pads make full contact and move freely after release
	Blocking of sanding system due to frozen ice/snow mixture	Wet snow Temperature: -10°C Duration: 30 min + 10 min hardening	▶ Sanding system is fully functional ▶ Minimum amount of sanding is achieved
	Malfunction of magnet disc brake due to snow accumulation and ice formation	Wet snow Temperature: -10°C Duration: 30 min + 10 min hardening	▶ Magnet disc brake is fully functional (raising and lowering) ▶ Clearance to top edge of rail is within permissible tolerance
	Malfunction of level control or tilting system due to snow accumulation and ice formation	Dry snow Temperature: -20°C Duration: 30 min Short rain + 10 min hardening	▶ Level control or tilting system are fully functional ▶ Clearance to top edge of rail is within permissible tolerance
Warning horn	Maximum sound level reduced or delayed due to accumulation of snow	Dry snow Temperature: -20°C Wind simulation Duration: 30 min (vehicle in regular operation).	▶ Sound level no more than 8 dB(A) below normal conditions and maximum sound level reached with a delay of less than 1 s according to EN 15153-2
Compressed air system	Ice formation due to water ingress	Vehicle switched off Temperature: -20°C (vehicle switched off)	▶ Compressor starts ▶ Air drying functions in defined range

Component	Problem	Climatic conditions	Requirements
Pantograph 	Pantograph cannot be raised due to ice build-up	Ice Ice thickness: approx. 3 mm Temperature: -10°C 10 min hardening	▸ Pantograph can be raised and lowered within defined range ▸ Contact force on contact wire is within specified tolerance
	Pantograph cannot be raised due to snow accumulation	Wet snow Snow thickness: approx. 3 cm Temperature: -10°C	▸ Pantograph can be raised and lowered within defined range ▸ Contact force on contact wire is within specified tolerance
Coupling 	Coupling process affected by ice build-up	Ice Ice thickness: approx. 2 mm Temperature: -20°C	▸ Mechanical and electrical coupling process is possible without restrictions
	Coupling process affected by snow accumulation	Wet snow Temperature: -10°C Duration: 30 min Dry snow Temperature: -20°C Duration: 30 min.	▸ Mechanical and electrical coupling process possible without restrictions ▸ No snow or water obstructions during the coupling process
Air conditioning	Improper functioning caused by ingress of dry snow	Dry snow Temperature: -20°C Wind: up to 30 kph Duration: 30 min (vehicle in regular operation).	▸ Proper functioning of air conditioning system (e.g. no reduction in fresh air supply) ▸ Snow (water) ingress causes no malfunction and is within specified tolerances
	Air conditioning unit switches off at extremely high outside temperatures	Extreme temperatures / rel. humidity levels 5 K (10 K) above application range	▸ Air conditioning system is fully functional
Sanitary facility	Water damage to sanitary facilities caused by frost	Temperature: -10°C Duration: 12 hours (vehicle switched off)	▸ No visible damage ▸ Sanitary facility fully functioning.

Component	Problem	Climatic conditions	Requirements
Windscreen heater, Windscreen wiper, Side mirror (Camera)	Impaired driver visibility during rain	Rain on windscreen Temperature: approx. +20°C Different driving speeds	▸ Streak-free removal of water film at all speeds ▸ No fogging of inside of windscreen
	Impaired driver visibility during snowfall	Wet snow on windscreen and side mirror Temperature: 0°C to -10°C Different driving speeds	▸ Streak-free removal of snow in the windscreen wiper range ▸ Proper functioning is not impaired by snow accumulation on wiper arm ▸ Side mirror fully functioning (e.g. tilting) and sufficient visibility
	De-icing of windscreen and side mirror insufficient	Ice Ice thickness: approx. 2 mm Temperature: -10°C to -20°C Hardening: 10 min (vehicle switched off)	▸ Removal of ice on windscreen and side mirror in specified time ▸ Windscreen wiper fully functioning after de-icing ▸ Side mirror fully functioning (e.g. tilting)
Traction	Diesel engine does not start at low temperatures	Cooling of vehicle to -20°C	▸ Starting procedure (preheating, starting etc) successful ▸ No noticeable problems in idle operation ▸ No performance reduction on dynamometer after operating temperature has been reached.
	Overheating of drive cooling system at high outside temperatures leads to performance reduction or failure of motor/engine	Different loading of cooling system on the dynamometer at climatic extremes of application range (different motor/engine and retarder ratings)	▸ Compliance with maximum permissible cooling circuit temperatures ▸ Performance reduction within permissible tolerance range
	Impairment of motor/engine cooling functions due to ingress of dry snow	Dry snow Temperature: -20°C Wind: up to 30 kph Duration: 30 min (vehicle in regular operation).	▸ Motor/engine cooling fully functional ▸ Snow (water) ingress causes no malfunction and is within specified tolerances

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